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EPA Contract No. 68-02-3512
Work Assignment No. 54
PEDCo Environmental Subcontract No. 500-83

AIR QUALITY IMPACT ASSESSMENT FOR ARSENIC EMISSIONS FROM THE ASARCO-TACOMA SMELTER

PRELIMINARY REPORT OF RESULTS
(Revised)

16 December 1983

Prepared for:

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1. SCOPE OF WORK

PEDCo Environmental, Inc. Subcontract No. 500-83 requires the H. E. Cramer Company, Inc. to perform the following tasks:

Task a.

Provide assistance to PEDCo Environmental, Inc. to update the 1976 background report ASARCO-Tacoma Arsenic Study in order to provide current information on the arsenic problem at the ASARCO-Tacoma smelter. Determine whether reasonably adequate meteorological data are available or can be made available for subsequent air quality modeling. This background review will necessitate that a representative of H. E. Cramer Company, Inc. attend meetings with the Puget Sound Air Pollution Control Agency (PSAPCA), EPA Region X and the ASARCO-Tacoma smelter.

Task b.

(1) Obtain from the Project Officer and Puget Sound Air Pollution Control Agency all available data on 24-hour ambient air quality concentrations of arsenic in the vicinity of the ASARCO-Tacoma smelter.

(2) Examine in detail the type of modeling techniques which are applicable to the topographic and meteorological situation and the source configuration at the ASARCO-Tacoma smelter. Select candidate model/models for projection of annual ground-level concentrations of arsenic to be applied to the ASARCO-Tacoma situation. Such models should include but not be limited to those recommended by EPA for this type of problem. The Project Officer must approve the model(s) utilized.

CORRECTION

THE PRECEDING DOCUMENTS HAVE BEEN

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(3) Perform model calculations for representative test cases from the available data.

Task c. Model Evaluation

Perform model evaluation studies including comparison of model estimates with observed data. Such studies shall include information on the accuracy and reliability of the model, an explanation of the difference between observations and estimates and a recommendation on the most appropriate model for further applications.

Task d. Model Application

(1) Using the annual diffusion modeling technique(s) determined by the Project Officer to be the most reliable, estimate the current concentration patterns of arsenic out to a distance of 20 km from the smelter. The emissions data and appropriate control information will be provided to the contractor by the Project Officer.

(2) Using the annual diffusion modeling technique(s) determined to be the most reliable, estimate the concentration patterns of arsenic out to 20 km from the smelter corresponding to stack and fugitive emission levels associated with varying levels of control and the probable locations of such maximum concentrations. The emissions data and appropriate control scenarios will be provided to the contractor by the Project Officer.

2. CONTENTS OF THE REPORT

Sections 3 and 4 of this report respectively contain summaries of the meteorological data and arsenic concentration measurements used in the selection and testing of candidate models options as well as in the model calculations of annual average arsenic concentrations for the Baseline and BAT emissions scenarios. The candidate models/model options selected for testing and evaluation are described in Section 5 and the the results of the model testing and evaluation are presented in Section 6. Model calculations for the Baseline and BAT emissions scenarios, including isopleth maps of the calculated arsenic concentration patterns, are described in Section 7. Suggestions for possible improvements in the modeling of low-level emissions to obtain better agreement between the calculated and measured arsenic concentrations for 1982 are presented in Section 8. An output data tape containing the model calculations for the Baseline and BAT emission scenarios in the ISCLT format was provided to Mr. George Duggan, EPA/SASD.

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3. ANALYSIS OF AVAILABLE METEOROLOGICAL DATA FOR THE TACOMA AREA

Table 3-1 lists the names, locations and measurement heights of the four meteorological stations closest to the ASARCO-Tacoma smelter. Wind measurements from these stations comprise the full set of candidate wind data available for use in model calculations of average quarterly and annual ground-level arsenic concentrations in the Tacoma area. Three of the four stations are located at N26th & Pearl in Tacoma which is about 3 km south of the Main Stack of the ASARCO smelter. The Tavern station is located about 200 m south of the Main Stack (see Figure 4-1).

Previous studies of the meteorology of the Tacoma area (Cramer, et al., 1976; Bowers, et al., 1982), have shown that the wind data from the three stations at N26th & Pearl provide the best available description of the transport of emissions from the ASARCO Main Stack. The Bowers, et al. (1982) study included a detailed analysis of the 1981 PSAPCA hourly SO_2 concentration data from N26th & Pearl in combination with the 1981 PSAPCA N26th & Pearl hourly wind data and the 1981 ASARCO 30-min average Benny's (N26th & Pearl) wind data. The Tower (N26th & Pearl) wind measurement height above mean sea level is about 50 m below the top of the ASARCO Main Stack.

We converted the 1982 Tower (N26th & Pearl) and Tavern 30-minute average wind directions and wind speeds to hourly averages for processing by the H. E. Cramer Company's Meteorological and Air Quality Statistical Analysis Program (MAQSAP). We then used the MAQSAP results to aid in selecting the wind data most suitable for modeling the arsenic emissions from the ASARCO smelter. The 1982 annual wind-direction distributions for the ASARCO Tower (N26th & Pearl) and Tavern sites are presented in Figure 3-1. The principal difference in these distribuitons is in the occurrence frequencies of winds from the north-northeast sector which are the wind directions required to transport emissions from the ASARCO smelter to

TABLE 3-1

UNIVERSAL TRANSVERSE MERCATOR (UTM) COORDINATES AND ELEVATIONS ABOVE MEAN SEA LEVEL (MSL) OF THE WIND MEASUREMENT SITES

Site	Operator	UTM X (km)	UTM Y (km)	Ground Elevation (m MSL)	Wind Measurement Height (m AGL)
Benny's (N26th & Pearl)	ASARCO	536.65	5,235.12	122	5.5
Tower (N26th & Pearl)	ASARCO	536.65	5,235.06	122	45.7
N26th & Pearl	PSAPCA	536.68	5,235.15	123	9.1
Tavern	ASARCO	537.31	5,237.87	55	18.3

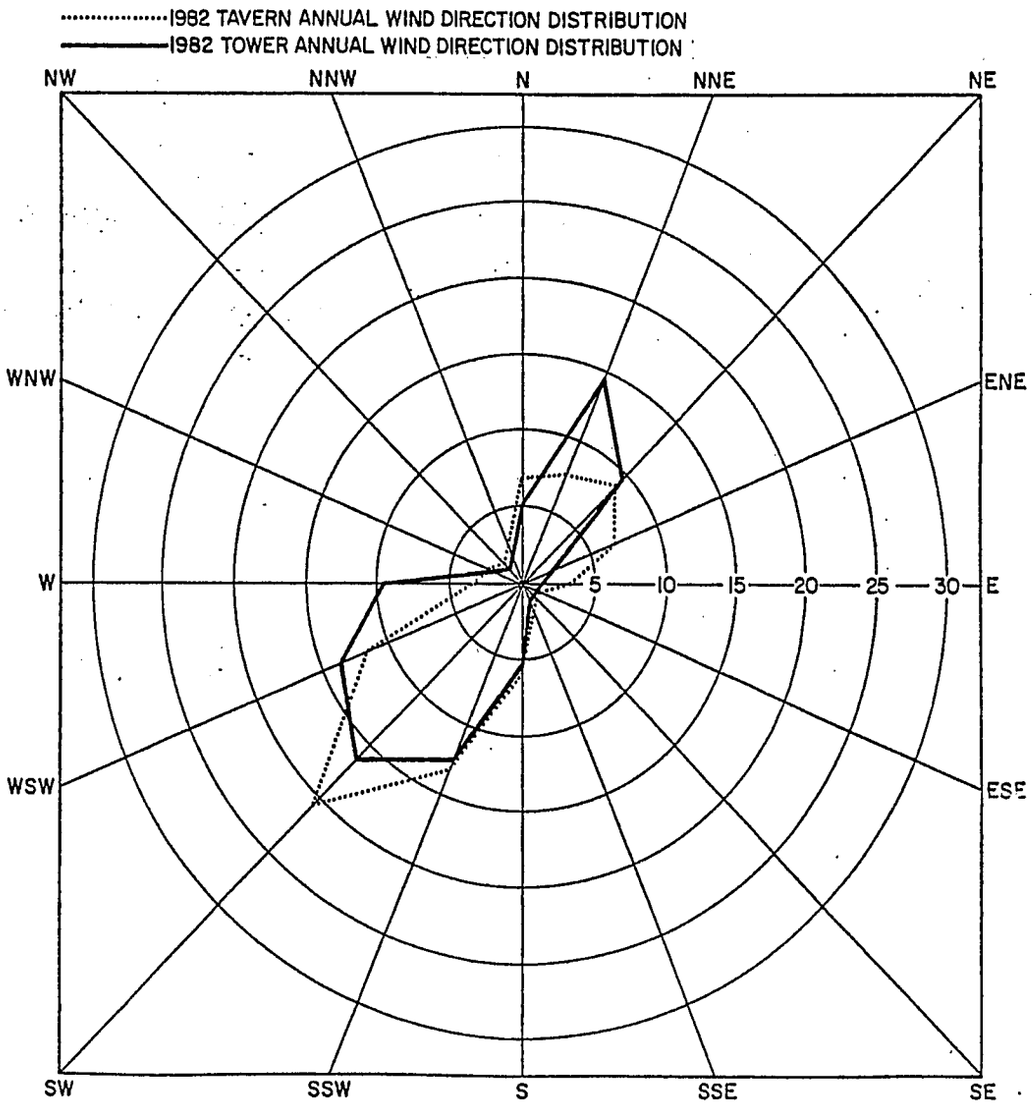

FIGURE 3-1. Annual 1982 wind-direction frequency distributions for the Tavern and Tower sites.

the nearby residential areas on the Tacoma peninsula. The frequency of north-northeast winds at the Tower site is about twice as large as at the Tavern site (14 percent versus about 8 percent). We believe that the differences in the annual wind distributions for the two sites are explained by differences in site roughness and in the height above ground of the meteorological sensors (45.7 m for the Tower site and 18.3 m for the Tavern site). Quarterly 1982 wind-frequency distributions for the Tower and Tavern sites are shown in Figure 3-2 and 3-3. These distributions exhibit the same difference in the frequencies of north-northeast winds at the two sites as the annual distributions.

We concluded that the ASARCO Tower wind data should be used in dispersion-model calculations of ground-level concentrations attributable to arsenic emissions from the ASARCO Main Stack and that the Tavern wind data should be used in modeling the arsenic emissions from all other sources. The 1982 hourly wind data from both the Tavern and Tower sites were combined with the 1982 cloud cover observations from McChord Air Force Base to develop quarterly STAR summaries (joint frequency distributions of wind speed and wind direction by Pasquill stability category) for each site. These quarterly STAR summaries were merged with in-stack SO_2 measurements and other emission curtailment data supplied by PEDCo to generate a matrix giving the emission rate for each arsenic source or source group (see Tables 6-1 and 6-2) by quarter, wind speed, wind direction and Pasquill stability category. The merged quarterly Tavern STAR summaries were used for all model calculations of quarterly and annual ground-level arsenic concentrations produced by all sources except the Main Stack. Similarly, the ASARCO Tower merged quarterly STAR summaries were used for all model calculations of the ground-level arsenic concentrations produced by the Main Stack. To determine the Pasquill stability categories at the ASARCO Tower site, the hourly mean wind speeds from the ASARCO Benny's 5.5-m level were used with the concurrent McChord ceiling-height and cloud-cover observations following the Turner (1964) procedures. Pasquill stability categories at the Tavern site were similarly determined from the Tavern 18.3-m hourly wind speeds and the concurrent McChord ceiling height and cloud cover observations.

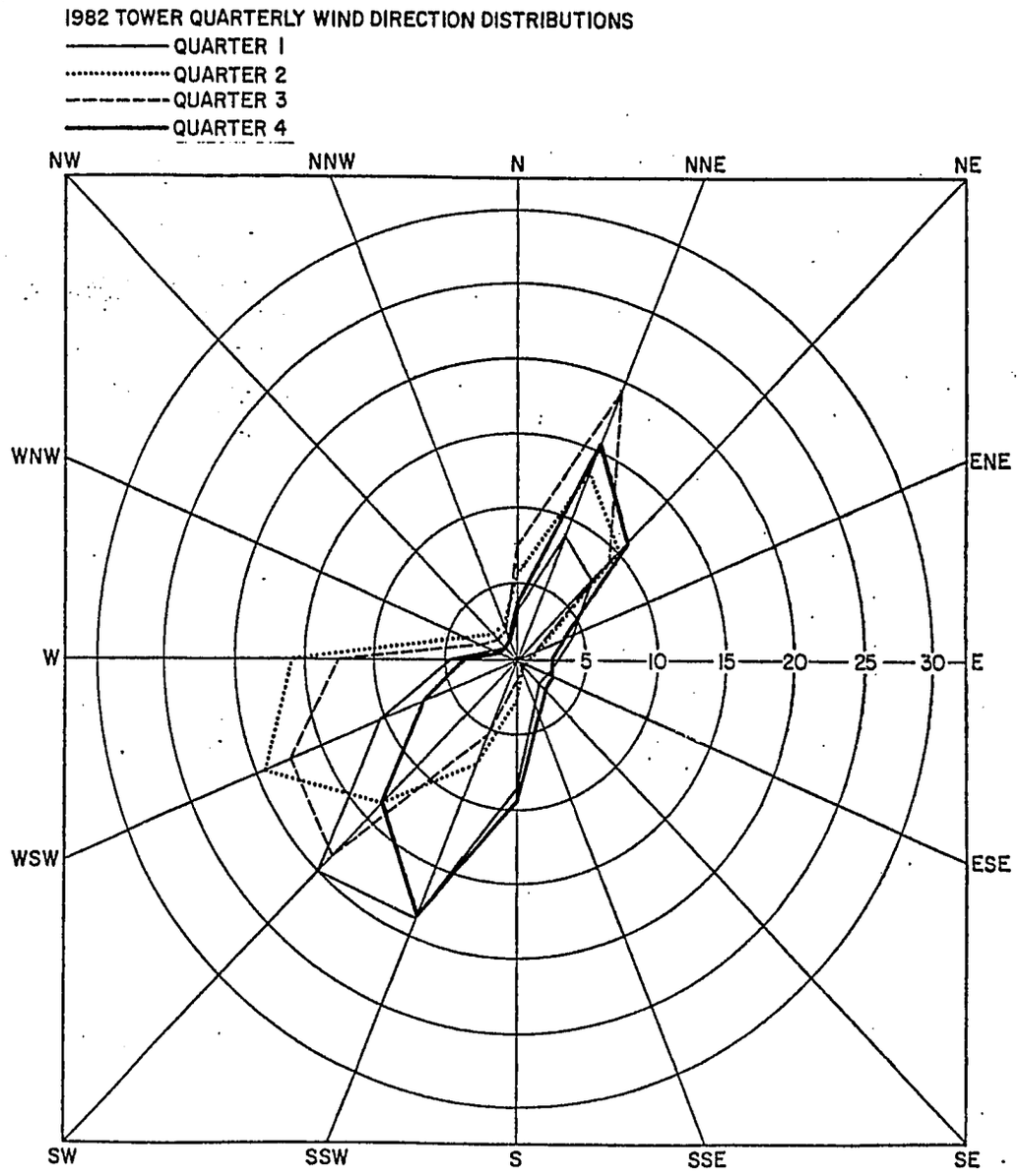

FIGURE 3-2. Quarterly 1982 wind-direction frequency distributions for the Tower site.

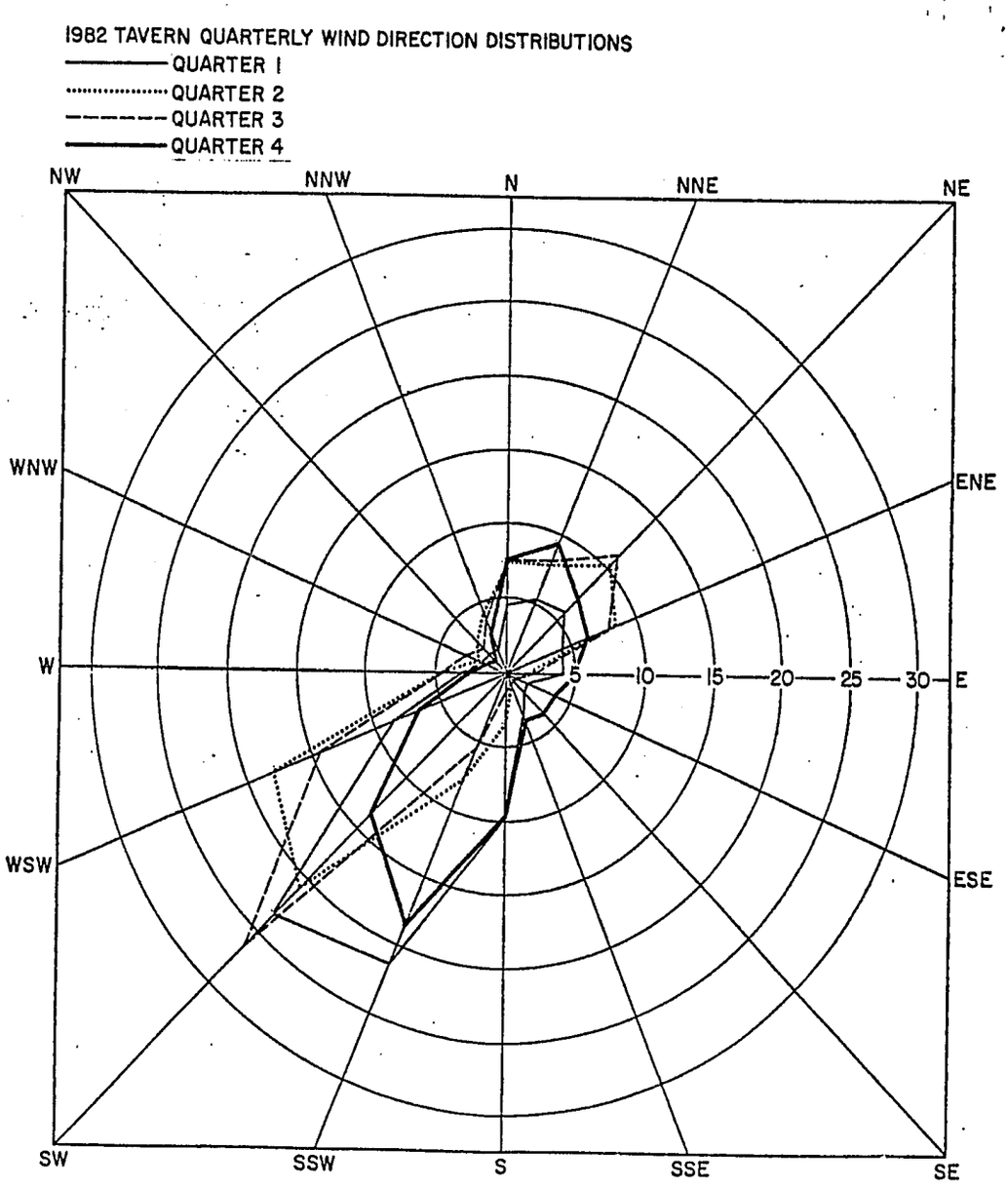

FIGURE 3-3. Quarterly 1982 wind-direction frequency distributions for the Tavern site.

Other meteorological data used in the model calculations including mixing heights and ambient air temperatures as well as other meteorological model inputs are described in Section 6.2.

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4. ANALYSIS OF AVAILABLE ARSENIC CONCENTRATION MEASUREMENTS IN THE TACOMA AREA

The only comprehensive measurements of arsenic concentrations in the Tacoma area are those made by ASARCO. The names and locations of the ASARCO arsenic monitoring stations are given in Table 4-1. The locations of the monitoring stations are also shown on a map of the Tacoma area in Figure 4-1. The three monitoring stations closest to the ASARCO smelter (Stack, Parking Lot, and Killenbeck) are operated on an approximate 24-hour schedule covering the time period from noon-to-noon plus or minus about 2 hrs. The 24-hr average concentration data from these stations are referred to as the "daily set". Arsenic concentrations at the other five monitoring stations are measured bi-weekly and are referred to as the "bi-weekly set". The arsenic concentration data from all eight stations was made available on magnetic tape for this study by ASARCO. The H. E. Cramer Company read the data from the tape and also supplied copies of the tape to PEDCo and EPA Region X. The results of a statistical analysis of the ASARCO data made by Region X were distributed to the H. E. Cramer Company, PEDCo and the Project Officer. Table 4-2 list the arithmetic mean and median arsenic concentrations calculated from the ASARCO data for each quarter and for all quarters of 1982. We point out that the large differences between the arithmetic means and medians at the Stack, Parking Lot and Killenbeck Stations are due to the presence of a relatively few very high 24-hr concentrations which affect the arithmetic means. If these very high 24-hr concentrations were caused by upset conditions at the arsenic sources, a question arises about the propriety of using the arithmetic means in comparing model calculations with measured concentrations because the arsenic emission rates used in the model calculations do not provide for upsets. Many of the very high 24-hour arsenic concentrations measured at the three "daily" stations did occur during days of "upset" conditions at the ASARCO Smelter as reported by ASARCO to the Puget Sound Air Pollution Control Agency (PSAPCA). However, the ASARCO reports to PSAPCA of

TABLE 4-1

NAMES AND LOCATIONS OF ASARCO ARSENIC MONITORING STATIONS

Station	UTM Coordinates		Elevation MSL (m)	Location	
	X (m)	Y (m)		Distance (m)	Azimuth* Bearing (deg)
Stack	537,310	5,237,870	55	484	195
Parking Lot	537,115	5,238,350	30	319	272
Killenbeck	536,790	5,237,760	64	865	228
Ruston	537,530	5,237,360	76	983	174
Reservoir	537,090	5,235,670	131	2,690	189
Benny's	536,650	5,235,120	122	3,312	194
Brown's Point	543,600	5,238,750	104	6,180	086
Vashon	538,100	5,249,300	104	10,982	003

* Distance and azimuth bearing are with respect to the center of the polar calculation grid (UTM coordinates are X = 537,434 m and Y = 5,238,338 m).

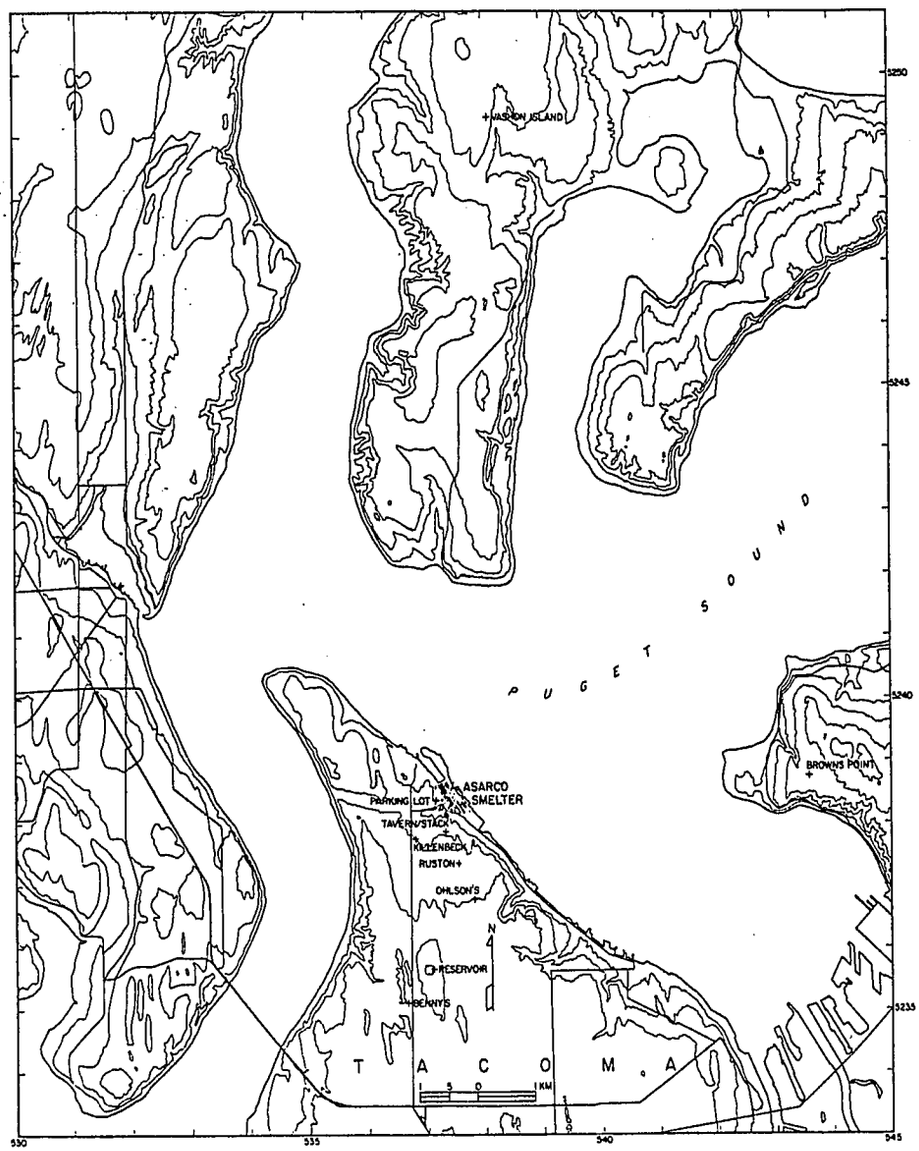

FIGURE 4-1. Map of the Tacoma area showing the locations of the ASARCO arsenic monitoring stations.

TABLE 4-2

1982 QUARTERLY AND ANNUAL ARSENIC CONCENTRATION MEASUREMENTS ($\mu g\ m^{-3}$)

Station	Quarter				Annual
	1	2	3	4	
Stack					
Mean (A)	0.732	1.870	0.884	2.204	1.507
Mean (X)	0.7	1.9	0.9	1.8	1.3
Median (X)	0.2	0.5	0.5	0.5	0.4
Parking Lot					
Mean (A)	0.654	0.911	0.458	0.990	0.755
Mean (X)	0.7	0.9	0.5	1.0	0.8
Median (X)	0.3	0.4	0.3	0.7	0.4
Killenbeck					
Mean (A)	0.321	0.964	0.537	0.505	0.582
Mean (X)	0.3	1.0	0.5	0.5	0.6
Median (X)	0.1	0.4	0.4	0.2	0.2
Ruston					
Mean (A)	0.135	0.270	0.360	0.275	0.261
Mean (X)	0.13	0.27	0.36	0.28	0.3
Median (X)	0.14	0.29	0.34	0.26	0.3
Reservoir					
Mean (A)	0.120	0.330	0.301	0.176	0.234
Mean (X)	0.12	0.33	0.31	0.18	0.2
Median (X)	0.09	0.35	0.29	0.20	0.2
Benny's					
Mean (A)	0.091	0.253	0.235	0.168	0.189
Mean (X)	0.08	0.26	0.24	0.17	0.2
Median (X)	0.06	0.27	0.24	0.18	0.2
Brown's Point					
Mean (A)	0.049	0.121	0.066	0.040	0.069
Mean (X)	0.05	0.12	0.07	0.04	0.1
Median (X)	0.06	0.09	0.04	0.03	0.1
Vashon Island					
Mean (A)	0.077	0.079	0.030	0.075	0.065
Mean (X)	0.08	0.08	0.03	0.08	0.1
Median (X)	0.08	0.07	0.03	0.07	0.1

* Letters in parenthesis indicate data source: (A) refers to ASARCO's tables and (X) refers to Region X's tables for unweighted "n-day" data sets.

"upset conditions" however are not sufficiently detailed to provide any insight as to the effects of these conditions or arsenic emissions. Information on the days during 1982 when ASARCO reported "upset conditions" was supplied to us by PEDCo from the PSAPCA files. At the five bi-weekly monitoring stations, the arithmetic means and medians are generally equivalent.

Table 4-3 lists the monthly average arsenic concentrations measured at the ASARCO monitoring stations during a five-month period in the summer and fall of 1980 when the smelter was closed because of a labor strike. We believe these measurements are the best ones to consider in estimating background arsenic concentrations. In Figure 4-2, the five-month average concentrations given in Table 4-3 are plotted against the distance of each station from the center of the polar calculation grid used for the Baseline and BAT model calculations which is located at Source No. 312 (see Table 6-2). It is evident from this plot that the "background" concentration estimates thus obtained decrease by about one order of magnitude with increasing distance from the Main Stack. This strong dependence on distance and the fact that only five months of data are available complicate the assignment of background concentrations at receptor locations other than the monitoring stations.

TABLE 4-3

1980 MONTHLY AVERAGE ARSENIC CONCENTRATION MEASUREMENTS ($\mu g\ m^{-3}$)
FROM JULY THROUGH NOVEMBER (PLANT CLOSED BY STRIKE)

Station	Month					All Months
	Jul	Aug	Sep	Oct	Nov	
Stack						
Mean (A)	0.153	0.123	0.093	0.164	0.095	0.126
Mean (X)	0.2	0.1	0.1	0.2	0.1	0.1
Median (X)	0.1	0.1	0.1	0.1	0.1	0.1
Parking Lot						
Mean (A)	0.053	0.171	0.070	0.199	0.296	0.158
Mean (X)	0.1	0.2	0.1	0.2	0.3	0.2
Median (X)	0.1	0.1	0.1	0.1	0.1	0.1
Killenbeck						
Mean (A)	0.081	0.083	0.075	0.132	0.087	0.092
Mean (X)	0.1	0.1	0.1	0.1	0.1	0.1
Median (X)	0.1	0.1	0.1	0.1	0.0	0.1
Ruston (A)	0.038	0.036	0.049	0.141	0.039	0.061
Reservoir (A)	0.040	0.030	0.022	0.048	0.025	0.033
Benny's (A)	0.039	0.040	0.032	0.077	0.015	0.041
Brown's Point (A)	0.019	0.035	0.020	0.015	0.020	0.022
Vashon Island (A)	0.015	0.030	0.014	0.035	0.031	0.025

* Letters in parenthesis indicate data source: (A) refers to ASARCO's tables and (X) refers to Region X's tables.

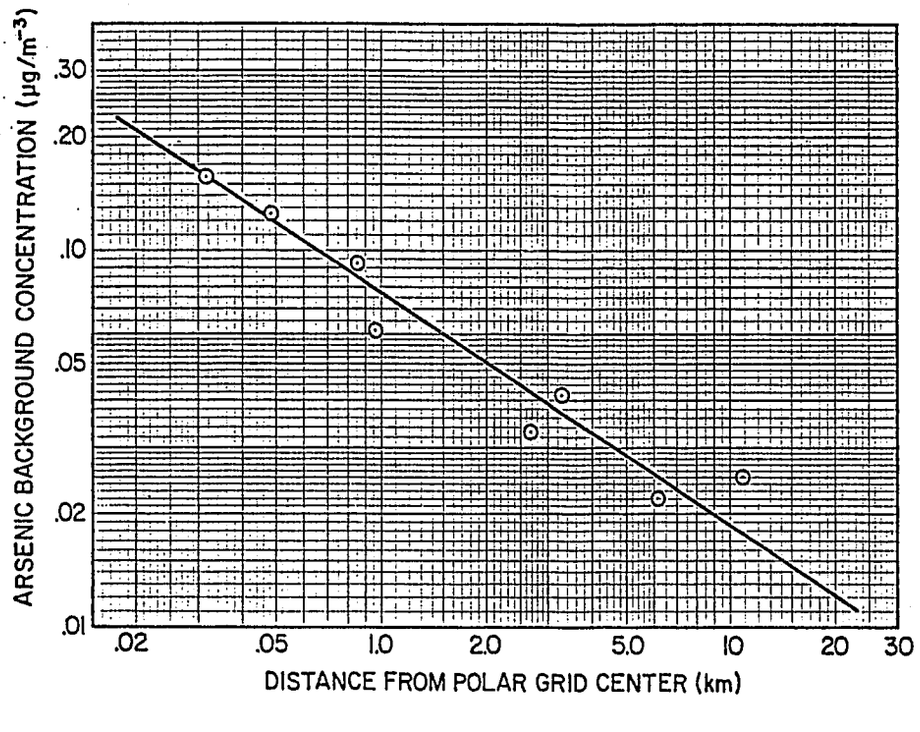

FIGURE 4-2. Plot of background arsenic concentration measurements at the ASARCO monitoring stations (arithmetic means for period from July through November 1980) versus distance from the polar grid center (Source 312). Solid line is least-squares regression fit to the data points.

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5. SELECTION OF CANDIDATE MODELS/MODEL OPTIONS

As the result of the work performed under Task b. of the PEDCo Subcontract, we identified two candidate long-term dispersion models, ISCLT and LONGZ, for evaluation with respect to projections of quarterly average ground-level concentrations of arsenic in the Tacoma area. Both models have the capability of handling the large number of sources and the various types of sources associated with arsenic emissions from the ASARCO-Tacoma smelter. Both models also have the capability of accepting emission rates which vary with time and meteorological conditions--a necessary feature because of the emission curtailment/control systems currently used at the ASARCO smelter. Additionally, both models are capable of calculating quarterly ground-level concentrations at a large number of receptor points so that the projected concentration field can be defined in adequate detail. Finally, both models have been used extensively for regulatory purposes and are well documented (Bjorklund and Bowers, 1982; Bowers, et al., 1979). In particular, the LONGZ model has been used to evaluate the long-term impact of SO_2 emissions from the main stack of the ASARCO-Tacoma smelter (Cramer, et al., 1976) as well as from other sources in and adjacent to the Tacoma tideflats area (Bowers, et al., 1982). In application in areas of complex terrain such as the Tacoma area, the ISCLT model is constrained such that a receptor elevation may not exceed the effective source height. This constraint does not affect the modeling of arsenic emissions from the Main Stack of the ASARCO-Tacoma smelter but does affect the modeling of arsenic emissions from all other sources. For simplicity, and from purely practical modeling considerations, we proposed to run the ISCLT model in the flat-terrain mode for all arsenic sources except the main stack. For the Main Stack emissions, we proposed to use the terrain adjustment option in ISCLT. Also, we proposed that all LONGZ model calculations be made using the terrain adjustment option for all sources.

In both the ISCLT and LONGZ models, there are Rural and Urban Mode Options. We proposed first to test ISCLT and LONGZ in their Rural Modes. In the event that the quarterly average ground-level concentrations

of arsenic thus calculated were significantly larger than the corresponding measurements at the monitor sites, we proposed to test both the Urban Mode of LONGZ and the Urban Mode 2 of ISCLT using the emissions from all sources except the Main Stack. We believe there is not adequate justification at present for using either Urban Mode to calculate the impact of arsenic emissions from the Main Stack. We point out that the use of the Urban Modes of both LONGZ and ISCLT affects only the vertical plume dispersion at short and intermediate distances (i.e. until the plumes are completely mixed in the surface mixing layer). The lateral plume dispersion is unaffected because the lateral plume dimensions are fixed by the dimensions of the 22.5-deg sectors of the long-term models.

Table 5-1 shows the matrix of the combinations of models, model options, terrain options and STAR summaries we proposed to use for Task c. In all model calculations, we proposed to combine the E and F Pasquill stability categories because we believe the default values for σ_z and the wind power-law exponent assigned to the F stability category do not occur near the ASARCO Smelter due to the presence of roughness elements and heat sources. The E and F stability categories were combined in the LONGZ and SHORTZ Rural Mode model calculations performed in the 1976 analysis of SO_2 emissions from the ASARCO-Tacoma Smelters (Cramer, et al., 1976).

The Project Officer approved the combinations of models and model options in Table 5-1 for use in the model evaluation studies under Task c.

TABLE 5-1

MATRIX OF MODELS/MODEL OPTIONS

Model/Mode/Terrain Option	Sources	STAR Summaries
First Choice		
LONGZ/Rural/Terrain Adjustment	Main Stack	ASARCO Tower
LONGZ/Rural/Terrain Adjustment	Low-Level	Tavern Tower
ISCLT/Rural/Terrain Adjustment	Main Stack	ASARCO Tower
ISCLT/Rural/Flat Terrain	Low-Level	Tavern Tower
Second Choice*		
LONGZ/Urban/Terrain Adjustment	Low-Level	Tavern Tower
ISCLT/Urban Mode 2/Flat Terrain	Low-Level	Tavern Tower

* To be used if the quarterly average arsenic concentrations calculated by the Rural Modes significantly exceed the corresponding arsenic concentrations measured at the monitor sites.

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6. MODEL TESTING AND EVALUATION USING 1982 EMISSIONS AND METEOROLOGICAL DATA

6.1 MODEL SOURCE INPUTS

The 1982 arsenic emissions data, including model source inputs and estimates of the effects of curtailment used to generate quarterly and annual emission rates for each source, were supplied by PEDCo and are contained in Section 4 and 5 of the PEDCo October 1983 Background Review. Table 6-1 lists the individual sources used in the LONGZ/ISCLT model calculations by name, source type and the source numbers appearing in the computer program listings. The first two digits of the source numbers in Table 6-1 are the same as the PEDCo source numbers and we added a third digit to accommodate the program model input requirements. Figure 4-3 on page 17 of the PEDCo October 1983 Background Review shows the layout of the ASARCO-Tacoma smelter and the locations of the sources listed in Table 6-1. The UTM coordinates and base elevations of the individual sources as well as their locations with respect to Source Number 312 (center of the polar calculation grid) are given in Table 6-2.

To account for the variability in arsenic emissions from sources directly affected by the SO_2 curtailment program at the ASARCO-Tacoma smelter, a methodology was devised for relating average SO_2 concentration measurements from the ASARCO Main Stack to meteorological conditions (see Section 5.2 of the PEDCo October 1983 Background Review). This methodology was used to generate quarterly and annual arsenic emission rates for each source affected by SO_2 curtailment by wind-speed, wind-direction and Pasquill stability category. The quarterly emission rates were used for model testing and evaluation. The annual emission rates were used in the Baseline and BAT model calculations (see Section 7). Figure 6-1 is a flow diagram showing the various steps in the methodology used to obtain the quarterly and annual arsenic emission rates for the sources affected by SO_2 curtailment. Input (1) in Figure 6-1 refers to tables of average hourly SO_2 emission rates by wind-speed and wind-direction category for each

TABLE 6-1

IDENTIFICATION OF ASARCO-TACOMA SOURCES USED IN THE LONGZ/ISCLT MODEL CALCULATIONS BY NAME, TYPE AND SOURCE NUMBER

Source Name	Type	LONGZ/ISCLT Source Number
Main Stack, Annual	Stack	100
Main Stack, First Quarter 1982	Stack	101
Main Stack, Second Quarter 1982	Stack	102
Main Stack, Third Quarter 1982	Stack	103
Main Stack, Fourth Quarter 1982	Stack	104
Multihearth Roasters	Area	200
Chemical ESP Conveyors	Area	210
Arsenic Conveyor 1	Area	221
Arsenic Conveyor 2	Area	222
Arsenic Conveyor 3	Area	223
Arsenic Conveyor 4	Area	224
Arsenic Conveyor 5	Area	225
Contrell Conveyors	Area	231 and 232
Roaster Baghouse	Area	240
Slag Dump	Area	251, 252, 253 and 254
Reverberatory Furnace	Building	300
Converters	Building	311, 312 and 313
Anode Furnace	Building	320
Godfrey Roasters and Material Handling	Building	331 and 332
Remaining Arsenic Plant	Building	340

TABLE 6-2

LOCATIONS AND BASE ELEVATIONS OF THE ASARCO ARSENIC SOURCES USED IN THE MODEL CALCULATIONS

LONGZ/ ISCLT Source No.	UTM Coordinates		Base Elevation (m)		Location *	
	X (m)	Y (m)	AGL	MSL	Distance (m)	Azimuth Bearing (deg)
100-104	537,350	5,238,080	172.2	45.7	271	198
200	537,465	5,238,224	18.6	15.2	118	165
210	537,660	5,238,156	10.0	10.6	290	129
221	537,478	5,238,173	18.6	15.2	171	165
222	537,500	5,238,178	18.6	15.2	173	158
223	537,518	5,238,198	16.5	8.8	163	155
224	537,547	5,238,217	14.3	7.3	166	137
225	537,570	5,238,236	12.1	7.3	170	127
231	537,330	5,238,206	10.0	24.4	168	218
232	537,330	5,238,182	10.0	24.4	187	214
240	537,453	5,238,204	18.0	14.6	135	172
251	537,129	5,239,067	3.0	6.0	780	337
252	537,147	5,239,049	3.0	6.0	767	338
253	537,165	5,239,031	3.0	6.0	743	339
254	537,183	5,239,013	3.0	6.0	720	340
300	537,408	5,238,304	24.1	10.1	43	217
311	537,412	5,238,360	26.8	7.3	31	315
312	537,434	5,238,338	26.8	7.3	0	0
313	537,456	5,238,316	26.8	7.3	31	135
320	537,386	5,238,398	26.2	7.9	77	245
331	537,417	5,238,237	18.0	14.0	103	189
332	537,435	5,238,218	18.0	14.0	120	180
340	537,400	5,238,195	12.5	21.3	147	193

* Distance and azimuth bearing are with respect to the center of the polar calculation grid (UTM coordinates are X = 537,434 m and Y = 5,238,338 m).

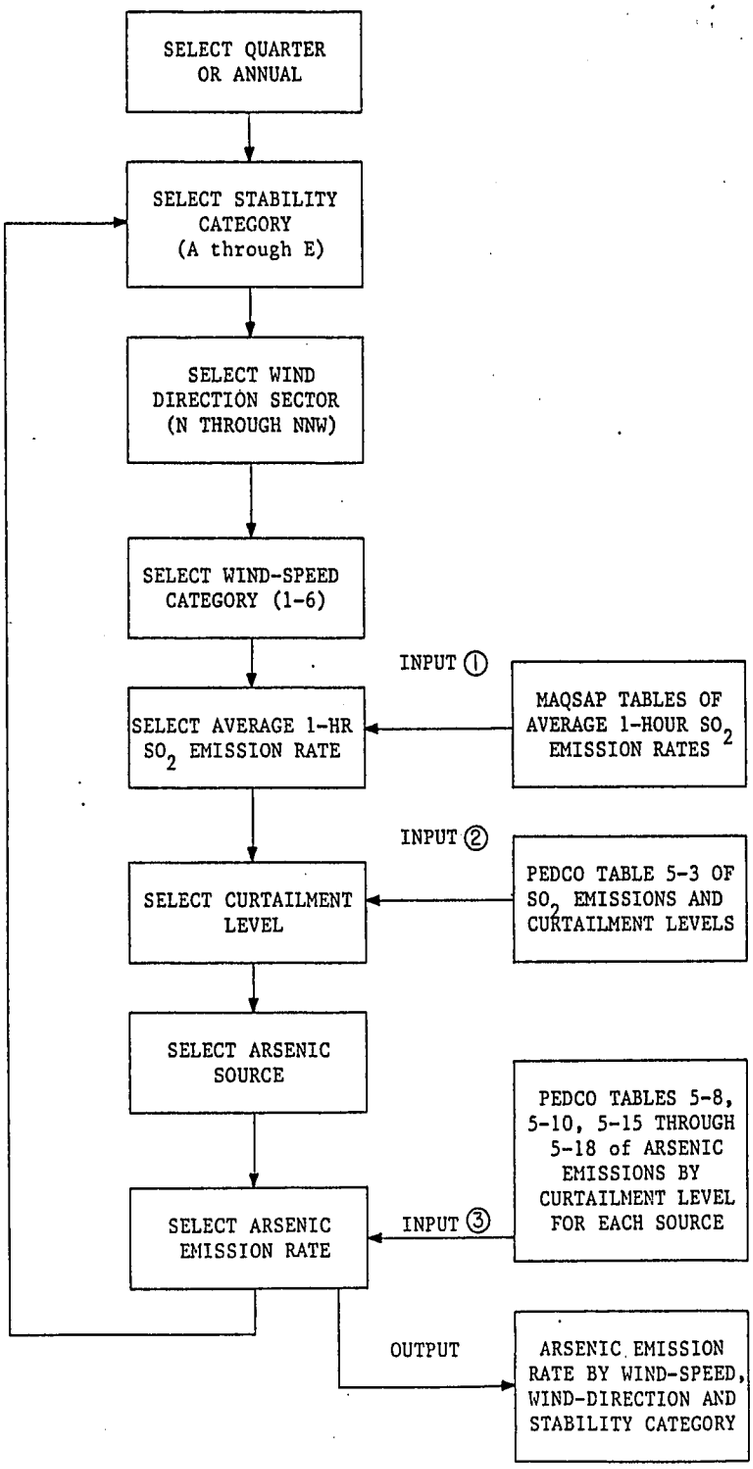

FIGURE 6-1. Flow diagram of steps in the calculation of arsenic emission rates.

Pasquill stability category. As indicated in Figure 6-1, there are 6 wind-speed categories, 16 wind-direction categories and 6 Pasquill stability categories. Quarterly and annual tables of average hourly SO_2 emission rates for both the Tavern and ASARCO Tower wind distributions were produced by the MAQSAP computer program. The tables for the Tavern wind distributions were used to obtain arsenic emission rates for all sources except the Main Stack and the tables for the ASARCO Tower wind distributions were used for the Main Stack emission rates. Inputs (2) and (3) in Figure 6-1 refer to tables in the PEDCo October 1983 Background Review. Tables 5-8 and 5-10 give the arsenic emission rates of each source by curtailment level for the annual Baseline and BAT emissions scenarios. Tables 5-15 through 5-18 give the arsenic emission rates of each source by curtailment level for the 1982 quarterly emissions. All of the steps in Figure 6-1 starting with the selection of a stability category are repeated for all combinations of stability category, wind-speed category, wind-direction sector and curtailment level for all sources. Tables of the quarterly and annual arsenic emission rates by wind-speed category, wind-direction sector and stability category for all sources were produced by computer using a program written for this purpose.

6.2 METEOROLOGICAL MODEL INPUTS

The meteorological inputs required by the computer programs on the LONGZ and ISCLT models are listed in Table 6-3. In addition to these inputs, the LONGZ computer program requires values for σ'_E; i,k which is the standard deviation of the wind-elevation angle (vertical turbulent intensity) in radians for the i^{th} wind-speed category and the k^{th} stability category (default values assigned on the basis of the Pasquill stability category). The default values for σ'_E for both rural and urban areas by Pasquill stability category are given in Table 2-3 of Bjorklund and Bowers (1982).

TABLE 6-3

METEOROLOGICAL INPUTS REQUIRED BY THE LONGZ AND ISCLT PROGRAMS

Input	Definition
$f_{i,j,k,\ell}$	Frequency distribution of wind-speed and wind-direction categories by stability categories for the ℓ^{th} season/quarter (STAR summary)
$\bar{u}\{z_R\}_i$	Mean wind speed (m/sec) at height z_R for the i^{th} wind-speed category (default values based on the standard STAR summary wind-speed categories)
$p_{i,k}$	Wind-profile exponent for the i^{th} wind-speed category and k^{th} stability category (default values assigned on the basis of wind speed and Pasquill stability category)
$T_{a;k,\ell}$	Ambient air temperature (^oK) for the k^{th} stability category and ℓ^{th} season/quarter
$\left(\frac{\partial\theta}{\partial z}\right)_{i,k}$	Vertical potential temperature gradient ($^oK/m$) for the i^{th} wind-speed category and k^{th} stability category
$H_{m,i,k,\ell}$	Median surface mixing depth (m) for the i^{th} wind-speed category, k^{th} stability category and ℓ^{th} season/quarter

Frequency distributions of wind speed and wind direction by Pasquill stability category (STAR summaries) were developed by the MAQSAP program for each quarter of 1982 using the 1982 hourly wind data from both the Tavern and Tower sites as outlined in Section 3. The mean wind speeds in Table 6-3 for the Tower site were obtained from the 1982 hourly mean wind speeds measured at the 5.5-m level at the ASARCO Benny's site. Similarly, at the Tavern site we used the 1982 hourly mean wind speeds measured at the 18.3-m level. To calculate the mean wind speeds at the height of plume stabilization and for emissions from the Main Stack and at other heights above the two reference measurement heights, we used the program default values for the wind-profile exponent with the mean wind speeds from the 5.5-m level at the ASARCO Benny's site and from the 18.3-m level at the Tavern site. Ambient air temperatures were obtained from the 1982 Station hourly temperature measurements listed on the meteorological data tape supplied by ASARCO. The default values given in Bjorklund and Bowers (1982) and in Bowers, et al. (1979) were used respectively for the vertical potential temperature gradient inputs to the LONGZ and ISCLT computer programs.

The mixing heights used in the LONGZ/ISCLT model calculations are presented in Table 6-4. The values in the table are based on an analysis of tabulations of early morning and afternoon mixing heights at the Seattle-Tacoma International Airport for the years 1959 through 1961 published by the Environmental Data Services in 1967 which were based on the Holzworth estimation techniques. The analysis of there mixing-height tabulations was made during one previous study for EPA of the air quality impact of SO_2 emissions from the ASARCO-Tacoma smelter (Cramer, et al., 1976). To the best of our knowledge, these are the most recent comprehensive mixing-height tabulations available for the Tacoma area. The time and effort required to develop similar tabulations using 1978 upper-air observations from the Seattle-Tacoma International Airport were beyond the scope of the present study. In using the mixing heights in Table 6-4 for the LONGZ/ISCLT model calculations, we substituted the base elevation of 122-m MSL of the ASARCO Tower site for the base elevation of 117-m MSL at the Seattle-Tacoma International Airport.

TABLE 6-4

MIXING HEIGHTS (m) USED IN THE LONGZ/ISCLT MODEL CALCULATIONS *

Stability Category	Wind Speed ($m\ s^{-1}$)					
	0-1.54	1.54-3.09	3.09-5.15	5.15-8.24	8.24-10.81	>10.81
First Quarter						
A	375	375	--	--	--	--
B	375	375	375	--	--	--
C	375	375	375	625	625	625
D	250	250	375	625	625	625
E	125	125	375	--	--	--
F	125	125	--	--	--	--
Second Quarter						
A	1250	1250	--	--	--	--
B	1250	1250	1250	--	--	--
C	1250	1250	1250	1250	1250	1250
D	690	810	960	1060	1250	1250
E	125	375	675	--	--	--
F	125	375	--	--	--	--
Third Quarter						
A	1250	1250	--	--	--	--
B	1250	1250	1250	--	--	--
C	1250	1250	1250	1250	1250	1250
D	690	810	810	940	1250	1250
E	125	375	375	--	--	--
F	125	375	--	--	--	--
Fourth Quarter						
A	625	875	--	--	--	--
B	625	875	875	--	--	--
C	625	875	875	875	875	875
D	375	500	625	875	875	875
E	125	125	375	--	--	--
F	125	125	--	--	--	--

* Dashes -- indicate combinations of stability and wind-speed categories which do not occur.

6.3 COMPARISON OF 1982 MODEL CALCULATIONS WITH MEASUREMENTS

Calculated and measured 1982 annual average arsenic concentrations together with the background estimates for the ASARCO monitoring stations are shown in Table 6-5. Similar quarterly 1982 data are shown in Table 6-6 through 6-9. In all cases, the measured concentrations are the annual arithmetic means from Table 4-2 calculated by ASARCO. Also, in all cases, the background concentrations are the 1980 five-month arithmetic means from Table 4-3.

In Tables 6-5 through 6-9, we added the background estimate to the calculated concentration and formed ratios of the measured concentration and the sum of the background and calculated concentrations at each monitor station. If this ratio is less than 1.0, it follows that the measured concentration is smaller than the calculated concentration adjusted for background. Because all the ratios in the tables are less than 1.0, the calculated concentrations (adjusted for background) are all larger than the corresponding measured values. Therefore, the model calculations (with or without the background adjustment) in all cases overestimate the measurements. The ratios in Table 6-5 for the monitor stations, which are closest to the smelter, range from 0.11 to 0.32 which means that the model values overpredict by factors ranging from about 9 to 3. Note that the use of median values instead of arithmetic means for the annual average measured concentrations at the Stack, Parking Lot and Killenbeck Stations (see Table 4-2) would lead to lower ratios at these stations and thus larger overpredictions. The ratios in Table 6-5 for the monitor stations farthest from the smelter range from 0.33 to 0.91 and the corresponding overprediction factors range from about 3.0 to 1.1. There is thus a significant improvement in the agreement between calculated and measured concentrations at the more distant monitoring stations with the best agreement (highest ratios) in almost all cases occurring at the most distant stations (Brown's Point and Vashon Island).

TABLE 6-5

RATIOS OF MEASURED AND CALCULATED 1982 ANNUAL AVERAGE ARSENIC CONCENTRATIONS (ADJUSTED FOR BACKGROUND) AT THE ASARCO MONITORING STATIONS
CONCENTRATIONS ARE IN $\mu g\ m^{-3}$ AND CALCULATED VALUES ARE FOR ALL SOURCES

	Station			
	Stack	Parking Lot	Killenbeck	Ruston
LONGZ Rural/Rural				
Calculated	6.084	6.558	2.339	1.555
Background*	0.126	0.158	0.092	0.061
Sum	6.210	6.716	2.431	1.616
Measured	1.507	0.755	0.582	0.261
Ratio	0.24	0.11	0.24	0.16
LONGZ Rural/Urban				
Calculated	4.783	5.190	1.734	1.184
Background*	0.126	0.158	0.092	0.061
Sum	4.909	5.348	1.826	1.245
Measured	1.507	0.755	0.582	0.261
Ratio	0.31	0.14	0.32	0.21
ISCLT Rural/Rural				
Calculated	6.323	5.939	3.427	2.362
Background*	0.126	0.158	0.092	0.061
Sum	6.449	6.097	3.519	2.423
Measured	1.507	0.755	0.582	0.261
Ratio	0.23	0.12	0.17	0.11
ISCLT Rural/Urban				
Calculated	5.730	5.747	2.452	1.842
Background*	0.126	0.158	0.092	0.061
Sum	5.856	5.905	2.544	1.903
Measured	1.507	0.755	0.582	0.261
Ratio	0.26	0.13	0.23	0.14

* Background concentrations are arithmetic means of ASARCO measurements for period from July through November 1980.

TABLE 6-5 (Continued)

RATIOS OF MEASURED AND CALCULATED 1982 ANNUAL AVERAGE ARSENIC CONCENTRATIONS (ADJUSTED FOR BACKGROUND) AT THE ASARCO MONITORING STATIONS
CONCENTRATIONS ARE IN $\mu g\ m^{-3}$ AND CALCULATED VALUES ARE FOR ALL SOURCES

	Station			
	Reservoir	Benny's	Brown's Point	Vashon Island
LONGZ Rural/Rural				
Calculated	0.297	0.227	0.069	0.047
Background*	0.033	0.041	0.022	0.025
Sum	0.330	0.268	0.091	0.072
Measured	0.234	0.189	0.069	0.065
Ratio	0.71	0.71	0.76	0.90
LONGZ Rural/Urban				
Calculated	0.251	0.200	0.064	0.046
Background*	0.033	0.041	0.022	0.025
Sum	0.284	0.241	0.086	0.071
Measured	0.234	0.189	0.069	0.065
Ratio	0.82	0.78	0.80	0.91
ISCLT Rural/Rural				
Calculated	0.679	0.500	0.130	0.086
Background*	0.033	0.041	0.022	0.025
Sum	0.712	0.541	0.152	0.111
Measured	0.234	0.189	0.069	0.065
Ratio	0.33	0.35	0.45	0.59
ISCLT Rural/Urban				
Calculated	0.440	0.318	0.076	0.058
Background*	0.033	0.041	0.022	0.025
Sum	0.473	0.359	0.098	0.083
Measured	0.234	0.189	0.069	0.065
Ratio	0.49	0.53	0.70	0.78

* Background concentrations are arithmetic means of ASARCO measurements for period from July through November 1980.

TABLE 6-6

RATIOS OF MEASURED AND CALCULATED 1982 FIRST QUARTER AVERAGE ARSENIC CONCENTRATIONS (ADJUSTED FOR BACKGROUND) AT THE ASARCO MONITORING STATIONS CONCENTRATIONS ARE IN $\mu g\ m^{-3}$ AND CALCULATED VALUES ARE FOR ALL SOURCES

	Station			
	Stack	Parking Lot	Killenbeck	Ruston
LONGZ Rural/Rural				
Calculated	4.170	9.531	2.056	0.987
Background*	0.126	0.158	0.092	0.061
Sum	4.296	9.689	2.148	1.048
Measured	0.732	0.654	0.321	0.135
Ratio	0.17	0.07	0.15	0.13
LONGZ Rural/Urban				
Calculated	3.240	7.494	1.501	0.747
Background*	0.126	0.158	0.092	0.061
Sum	3.366	7.652	1.593	0.808
Measured	0.732	0.654	0.321	0.135
Ratio	0.22	0.09	0.20	0.17
ISCLT Rural/Rural				
Calculated	4.294	8.048	3.085	1.525
Background*	0.126	0.158	0.092	0.061
Sum	4.420	8.206	3.177	1.586
Measured	0.732	0.654	0.321	0.135
Ratio	0.17	0.08	0.10	0.09
ISCLT Rural/Urban				
Calculated	3.915	8.126	2.228	1.190
Background*	0.126	0.158	0.092	0.061
Sum	4.041	8.284	2.320	1.251
Measured	0.732	0.654	0.321	0.135
Ratio	0.18	0.08	0.14	0.11

* Background concentrations are arithmetic means of ASARCO measurements for period from July through November 1980.

TABLE 6-6 (Continued)

RATIOS OF MEASURED AND CALCULATED 1982 FIRST QUARTER AVERAGE ARSENIC CONCENTRATIONS (ADJUSTED FOR BACKGROUND) AT THE ASARCO MONITORING STATIONS CONCENTRATIONS ARE IN $\mu g\ m^{-3}$ AND CALCULATED VALUES ARE FOR ALL SOURCES

	Station			
	Reservoir	Benny's	Brown's Point	Vashon Island
LONGZ Rural/Rural				
Calculated	0.202	0.165	0.062	0.093
Background*	0.033	0.041	0.022	0.025
Sum	0.235	0.206	0.084	0.118
Measured	0.120	0.091	0.049	0.077
Ratio	0.51	0.44	0.58	0.62
LONGZ Rural/Urban				
Calculated	0.172	0.150	0.061	0.093
Background*	0.033	0.041	0.022	0.025
Sum	0.205	0.191	0.083	0.118
Measured	0.120	0.091	0.049	0.077
Ratio	0.59	0.48	0.59	0.65
ISCLT Rural/Rural				
Calculated	0.460	0.357	0.116	0.152
Background*	0.033	0.041	0.022	0.025
Sum	0.493	0.398	0.138	0.177
Measured	0.120	0.091	0.049	0.077
Ratio	0.24	0.23	0.36	0.44
ISCLT Rural/Urban				
Calculated	0.285	0.217	0.073	0.113
Background*	0.033	0.041	0.022	0.025
Sum	0.318	0.258	0.095	0.138
Measured	0.120	0.091	0.049	0.077
Ratio	0.38	0.35	0.52	0.56

* Background concentrations are arithmetic means of ASARCO measurements for period from July through November 1980.

TABLE 6-7

RATIOS OF MEASURED AND CALCULATED 1982 SECOND QUARTER AVERAGE ARSENIC CONCENTRATIONS (ADJUSTED FOR BACKGROUND) AT THE ASARCO MONITORING STATIONS CONCENTRATIONS ARE IN $\mu g\ m^{-3}$ AND CALCULATED VALUES ARE FOR ALL SOURCES

	Station			
	Stack	Parking Lot	Killenbeck	Ruston
LONGZ Rural/Rural				
Calculated	7.871	5.478	2.901	2.144
Background*	0.126	0.158	0.092	0.061
Sum	7.997	5.636	2.993	2.205
Measured	1.870	0.911	0.964	0.270
Ratio	0.23	0.16	0.32	0.12
LONGZ Rural/Urban				
Calculated	6.203	4.433	2.165	1.624
Background*	0.126	0.158	0.092	0.061
Sum	6.329	4.591	2.257	1.685
Measured	1.870	0.911	0.964	0.270
Ratio	0.30	0.20	0.43	0.16
ISCLT Rural/Rural				
Calculated	7.990	4.989	4.103	3.190
Background*	0.126	0.158	0.092	0.061
Sum	8.116	5.147	4.195	3.251
Measured	1.870	0.911	0.964	0.270
Ratio	0.23	0.18	0.23	0.08
ISCLT Rural/Urban				
Calculated	7.156	4.752	2.899	2.451
Background*	0.126	0.158	0.092	0.061
Sum	7.282	4.910	2.991	2.512
Measured	1.870	0.911	0.964	0.270
Ratio	0.26	0.19	0.32	0.11

* Background concentrations are arithmetic means of ASARCO measurements for period from July through November 1980.

TABLE 6-7 (Continued)

RATIOS OF MEASURED AND CALCULATED 1982 SECOND QUARTER AVERAGE ARSENIC CONCENTRATIONS (ADJUSTED FOR BACKGROUND) AT THE ASARCO MONITORING STATIONS CONCENTRATIONS ARE IN $\mu g\ m^{-3}$ AND CALCULATED VALUES ARE FOR ALL SOURCES

	Station			
	Reservoir	Benny's	Brown's Point	Vashon Island
LONGZ Rural/Rural				
Calculated	0.394	0.296	0.094	0.013
Background*	0.033	0.041	0.022	0.025
Sum	0.427	0.337	0.116	0.038
Measured	0.330	0.253	0.121	0.079
Ratio	0.77	0.75	1.04	2.08
LONGZ Rural/Urban				
Calculated	0.327	0.255	0.083	0.012
Background*	0.033	0.041	0.022	0.025
Sum	0.360	0.296	0.105	0.037
Measured	0.330	0.253	0.121	0.079
Ratio	0.92	0.85	1.15	2.14
ISCLT Rural/Rural				
Calculated	0.884	0.646	0.164	0.037
Background*	0.033	0.041	0.022	0.025
Sum	0.917	0.687	0.186	0.062
Measured	0.330	0.253	0.121	0.079
Ratio	0.36	0.37	0.65	1.27
ISCLT Rural/Urban				
Calculated	0.579	0.419	0.088	0.018
Background*	0.033	0.041	0.022	0.025
Sum	0.612	0.460	0.110	0.043
Measured	0.330	0.253	0.121	0.079
Ratio	0.54	0.55	1.10	1.84

* Background concentrations are arithmetic means of ASARCO measurements for period from July through November 1980.

TABLE 6-8

RATIOS OF MEASURED AND CALCULATED 1982 THIRD QUARTER AVERAGE ARSENIC CONCENTRATIONS (ADJUSTED FOR BACKGROUND) AT THE ASARCO MONITORING STATIONS CONCENTRATIONS ARE IN $\mu g\ m^{-3}$ AND CALCULATED VALUES ARE FOR ALL SOURCES

	Station			
	Stack	Parking Lot	Killenbeck	Ruston
LONGZ Rural/Rural				
Calculated	7.089	2.711	2.561	1.969
Background*	0.126	0.158	0.092	0.061
Sum	7.215	2.869	2.653	2.030
Measured	0.884	0.458	0.537	0.360
Ratio	0.12	0.16	0.20	0.18
LONGZ Rural/Urban				
Calculated	5.641	2.162	1.914	1.517
Background*	0.126	0.158	0.092	0.061
Sum	5.767	2.320	2.006	1.578
Measured	0.884	0.458	0.537	0.360
Ratio	0.15	0.20	0.27	0.23
ISCLT Rural/Rural				
Calculated	7.421	2.733	3.720	2.964
Background*	0.126	0.158	0.092	0.061
Sum	7.547	2.891	3.812	3.025
Measured	0.884	0.458	0.537	0.360
Ratio	0.12	0.16	0.14	0.12
ISCLT Rural/Urban				
Calculated	6.769	2.530	2.659	2.364
Background*	0.126	0.158	0.092	0.061
Sum	6.895	2.688	2.751	2.425
Measured	0.884	0.458	0.537	0.360
Ratio	0.13	0.17	0.20	0.15

* Background concentrations are arithmetic means of ASARCO measurements for period from July through November 1980.

TABLE 6-8 (Continued)

RATIOS OF MEASURED AND CALCULATED 1982 THIRD QUARTER AVERAGE ARSENIC CONCENTRATIONS (ADJUSTED FOR BACKGROUND) AT THE ASARCO MONITORING STATIONS CONCENTRATIONS ARE IN $\mu g\ m^{-3}$ AND CALCULATED VALUES ARE FOR ALL SOURCES

	Station			
	Reservoir	Benny's	Brown's Point	Vashon Island
LONGZ Rural/Rural				
Calculated	0.361	0.266	0.073	0.015
Background*	0.033	0.041	0.022	0.025
Sum	0.394	0.307	0.095	0.040
Measured	0.301	0.235	0.066	0.030
Ratio	0.76	0.77	0.69	0.75
LONGZ Rural/Urban				
Calculated	0.313	0.240	0.067	0.014
Background*	0.033	0.041	0.022	0.025
Sum	0.346	0.281	0.089	0.039
Measured	0.301	0.235	0.066	0.030
Ratio	0.87	0.84	0.74	0.77
ISCLT Rural/Rural				
Calculated	0.818	0.582	0.143	0.030
Background*	0.033	0.041	0.022	0.025
Sum	0.851	0.623	0.165	0.055
Measured	0.301	0.235	0.066	0.030
Ratio	0.35	0.38	0.40	0.55
ISCLT Rural/Urban				
Calculated	0.553	0.387	0.086	0.020
Background*	0.033	0.041	0.022	0.025
Sum	0.586	0.428	0.108	0.045
Measured	0.301	0.235	0.066	0.030
Ratio	0.51	0.55	0.61	0.67

* Background concentrations are arithmetic means of ASARCO measurements for period from July through November 1980.

TABLE 6-9

RATIOS OF MEASURED AND CALCULATED 1982 FOURTH QUARTER AVERAGE ARSENIC CONCENTRATIONS (ADJUSTED FOR BACKGROUND) AT THE ASARCO MONITORING STATIONS CONCENTRATIONS ARE IN $\mu g\ m^{-3}$ AND CALCULATED VALUES ARE FOR ALL SOURCES

	Station			
	Stack	Parking Lot	Killenbeck	Ruston
LONGZ Rural/Rural				
Calculated	5.207	8.513	1.838	1.121
Background*	0.126	0.158	0.092	0.061
Sum	5.333	8.671	1.930	1.182
Measured	2.204	0.990	0.505	0.275
Ratio	0.41	0.11	0.26	0.23
LONGZ Rural/Urban				
Calculated	4.050	6.671	1.356	0.846
Background*	0.126	0.158	0.092	0.061
Sum	4.176	6.829	1.448	0.907
Measured	2.204	0.990	0.505	0.275
Ratio	0.53	0.14	0.35	0.30
ISCLT Rural/Rural				
Calculated	5.614	7.985	2.802	1.768
Background*	0.126	0.158	0.092	0.061
Sum	5.740	8.143	2.894	1.829
Measured	2.204	0.990	0.505	0.275
Ratio	0.38	0.12	0.17	0.15
ISCLT Rural/Urban				
Calculated	5.082	7.579	2.024	1.362
Background*	0.126	0.158	0.092	0.061
Sum	5.208	7.737	2.116	1.423
Measured	2.204	0.990	0.505	0.275
Ratio	0.42	0.13	0.24	0.19

* Background concentrations are arithmetic means of ASARCO measurements for period from July through November 1980.

TABLE 6-9 (Continued)

RATIOS OF MEASURED AND CALCULATED 1982 FOURTH QUARTER AVERAGE ARSENIC CONCENTRATIONS (ADJUSTED FOR BACKGROUND) AT THE ASARCO MONITORING STATIONS
CONCENTRATIONS ARE IN $\mu g\ m^{-3}$ AND CALCULATED VALUES ARE FOR ALL SOURCES

	Station			
	Reservoir	Benny's	Brown's Point	Vashon Island
LONGZ Rural/Rural				
Calculated	0.233	0.182	0.046	0.066
Background*	0.033	0.041	0.022	0.025
Sum	0.266	0.223	0.068	0.091
Measured	0.176	0.168	0.040	0.075
Ratio	0.66	0.75	0.59	0.82
LONGZ Rural/Urban				
Calculated	0.193	0.157	0.044	0.065
Background*	0.033	0.041	0.022	0.025
Sum.	0.226	0.198	0.066	0.090
Measured	0.176	0.168	0.040	0.075
Ratio	0.78	0.85	0.61	0.83
ISCLT Rural/Rural				
Calculated	0.553	0.417	0.097	0.123
Background*	0.033	0.041	0.022	0.025
Sum	0.586	0.458	0.119	0.148
Measured	0.176	0.168	0.040	0.075
Ratio	0.30	0.37	0.34	0.51
ISCLT Rural/Urban				
Calculated	0.342	0.249	0.059	0.083
Background*	0.033	0.041	0.022	0.025
Sum	0.375	0.290	0.081	0.108
Measured	0.176	0.168	0.040	0.075
Ratio	0.47	0.58	0.49	0.69

* Background concentrations are arithmetic means of ASARCO measurements for period from July through November 1980.

To assist in interpreting the results shown in Tables 6-5 through 6-9, it is of interest to identify the contributions of individual arsenic sources to the calculated concentrations at each monitoring station. The sources contributing more than 5 percent of the total calculated concentration for all sources at each monitor site for each of the four model options are identified in Tables 6-10 through 6-13. In all cases, the Converters (Source Numbers 311-313; see Table 6-1) are the major contributors and account for 45 to 68 percent of the total concentration calculated for all sources. The Godfrey Roasters and Material Handling sources (Source Numbers 331 and 332) and the Reverberatory Furnace (Source Number 300) are the next most important contributors and each accounts for about 10 to 20 percent of the total.

Because of the model overprediction problem described above and the need to meet the 11 November 1983 schedule for production runs of the Baseline and BAT emissions scenarios, it was not possible to do any additional work on the model testing and evaluation task. With the concurrence of the Project Officer, we selected the model/mode option to be used in the production runs which we believed to be best suited for this purpose on the basis of our best technical judgment and our experience. On this basis, we selected the LONGZ Rural/Urban Mode combination option. First, this combination produced the highest ratio values in the comparisons of model predictions with arsenic concentrations measured at the ASARCO monitoring stations (see Tables 6-5). Also the LONGZ model has been used successfully in the Tacoma area and in other complex terrain situations. ISCLT is not strictly applicable in complex terrain because of the restriction that the effective source height may not be less than the receptor elevation.

TABLE 6-10

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED 1982 ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT THE ASARCO MONITORING STATIONS

Station	Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
LONGZ RURAL/RURAL				
Stack	All Sources	6.0842		
	311-313		3.1406	51.62
	331-332		1.3088	21.51
	300		0.8173	13.43
	340		0.3588	5.90
				Total 92.46
Parking Lot	All Sources	6.5580		
	311-313		4.4611	68.03
	300		0.8282	12.63
	331-332		0.7812	11.91
				Total 92.57
Killenbeck	All Sources	2.3392		
	311-313		1.3105	56.02
	331-332		0.4323	18.48
	300		0.3283	14.03
				Total 88.53
Ruston	All Sources	1.5553		
	311-313		0.8877	57.08
	331-332		0.2763	17.77
	300		0.2185	14.05
				Total 88.90

TABLE 6-10 (Continued)

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED 1982 ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT THE ASARCO MONITORING STATIONS

Station	Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
LONGZ RURAL/RURAL				
Reservoir	All Sources	0.2974		
	311-313		0.1680	56.49
	331-332		0.0439	14.76
	300		0.0421	14.16
	101-104		0.0140	4.71
				Total 90.12
Benny's	All Sources	0.2270		
	311-313		0.1223	53.88
	331-332		0.0309	13.61
	300		0.0305	13.44
	101-104		0.0223	9.82
				Total 90.75
Brown's Point	All Sources	0.0689		
	311-313		0.0309	44.85
	101-104		0.0188	27.29
	300		0.0079	11.47
	331-332		0.0066	9.58
				Total 93.19
Vashon Island	All Sources	0.0468		
	311-313		0.0264	56.41
	101-104		0.0064	13.68
	300		0.0062	13.25
	331-332		0.0045	9.62
				Total 92.96

TABLE 6-11

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED 1982 ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT THE ASARCO MONITORING STATIONS

Station	Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
LONGZ RURAL/URBAN				
Stack	All Sources	4.7834		
	311-313		2.4779	51.80
	331-332		1.0189	21.30
	300		0.6463	13.51
	340		0.2720	5.69
				Total 92.30
Parking Lot	All Sources	5.1900		
	311-313		3.5400	68.21
	300		0.6579	12.68
	331-332		0.6100	11.75
				Total 92.64
Killenbeck	All Sources	1.7340		
	311-313		0.9742	56.18
	331-332		0.3170	18.28
	300		0.2448	14.12
				Total 88.58
Ruston	All Sources	1.1840		
	311-313		0.6779	57.26
	331-332		0.2074	17.52
	300		0.1672	14.12
				Total 88.90

TABLE 6-11 (Continued)

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED 1982 ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT THE ASARCO MONITORING STATIONS

Station	Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
LONGZ RURAL/URBAN				
Reservoir	All Sources	0.2514		
	311-313		0.1418	56.40
	331-332		0.0358	14.24
	300		0.0355	14.12
	101-104		0.0140	5.57
				Total 90.33
Benny's	All Sources	0.2002		
	311-313		0.1069	53.40
	300		0.0267	13.34
	331-332		0.0263	13.14
	101-104		0.0223	11.14
				Total 91.02
Brown's Point	All Sources	0.0639		
	311-313		0.0279	43.66
	101-104		0.0188	29.42
	300		0.0071	11.11
	331-332		0.0059	9.23
				Total 93.42
Vashon Island	All Sources	0.0461		
	311-313		0.0259	56.18
	101-104		0.0064	13.88
	300		0.0060	13.02
	331-332		0.0044	9.54
				Total 92.62

TABLE 6-12

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED 1982 ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT THE ASARCO MONITORING STATIONS

Station	Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
ISCLT RURAL/RURAL				
Stack	All Sources	6.3298		
	311-313		2.8435	44.92
	331-332		1.4446	22.82
	300		0.7695	12.16
	340		0.5728	9.05
				Total 88.95
Parking Lot	All Sources	5.9386		
	311-313		3.7252	62.73
	331-332		0.8483	14.28
	300		0.6841	11.52
				Total 88.53
Killenbeck	All Sources	3.4273		
	311-313		1.8424	53.76
	331-332		0.6440	18.79
	300		0.4562	13.31
	340		0.2120	6.19
				Total 92.05
Ruston	All Sources	2.3619		
	311-313		1.2317	52.15
	331-332		0.4461	18.89
	300		0.3191	13.51
	340		0.1397	5.91
				Total 90.46

TABLE 6-12 (Continued)

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED 1982 ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT THE ASARCO MONITORING STATIONS

Station	Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
ISCLT RURAL/RURAL				
Reservoir	All Sources	0.6789		
	311-313		0.3827	56.37
	331-332		0.1114	16.41
	300		0.0977	14.39
	101-104		0.0051	0.75
			Total	87.92
Benny's	All Sources	0.5003		
	311-313		0.2844	56.85
	331-332		0.0798	15.95
	300		0.0722	14.43
	101-104		0.0057	1.14
			Total	88.37
Brown's Point	All Sources	0.1300		
	311-313		0.0754	58.00
	300		0.0195	15.00
	331-332		0.0178	13.69
	101-104		0.0043	3.31
			Total	90.00
Vashon Island	All Sources	0.0855		
	311-313		0.0529	61.87
	300		0.0124	14.50
	331-332		0.0099	11.58
	101-104		0.0028	3.27
			Total	91.22

TABLE 6-13

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED 1982 ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT THE ASARCO MONITORING STATIONS

Station	Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
ISCLT RURAL/URBAN 2				
Stack	All Sources	5.7304		
	311-313		2.6253	45.81
	331-332		1.2559	21.92
	300		0.7462	13.02
	340		0.4758	8.30
				Total 89.05
Parking Lot	All Sources	5.7466		
	311-313		3.7088	64.54
	331-332		0.7591	13.21
	300		0.6807	11.84
				Total 89.59
Killenbeck	All Sources	2.4524		
	311-313		1.3227	53.93
	331-332		0.4425	18.04
	300		0.3400	13.86
	340		0.1421	5.79
				Total 91.62
Ruston	All Sources	1.8419		
	311-313		0.9887	53.68
	331-332		0.3326	18.06
	300		0.2605	14.14
	340		0.0978	5.31
				Total 91.19

TABLE 6-13 (Continued)

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED 1982 ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT THE ASARCO MONITORING STATIONS

Station	Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
ISCLT RURAL/URBAN 2				
Reservoir	All Sources	0.4400		
	311-313		0.2506	56.95
	331-332		0.0694	15.77
	300		0.0645	14.66
	101-104		0.0051	1.16
				Total 88.54
Benny's	All Sources	0.3180		
	311-313		0.1819	57.20
	331-332		0.0488	15.35
	300		0.0465	14.62
	101-104		0.0057	1.79
				Total 88.96
Brown's Point	All Sources	0.0765		
	311-313		0.0437	57.12
	300		0.0113	14.77
	331-332		0.0099	12.94
	101-104		0.0043	5.62
				Total 90.45
Vashon Island	All Sources	0.0585		
	311-313		0.0357	61.03
	300		0.0083	14.19
	331-332		0.0066	11.28
	101-104		0.0028	4.79
				Total 91.29

7. RESULTS OF MODEL CALCULATIONS FOR THE BASELINE AND BAT EMISSIONS SCENARIOS

The emissions data used in the Baseline and BAT model calculations were supplied by PEDCo. The Source Names and LONGZ Source Numbers are the same as those in Table 6-1. The source locations and base elevations are the same as those in Table 6-2. We used a polar calculation grid with 16 radials at angular increments of 22.5 deg beginning at north. The distances in kilometers along each radial at which receptors were located are as follows: 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15.0, 16.0, 17.0, 18.0, 19.0 and 20.0. The UTM coordinates of the origin of the polar grid are X = 537,434 meters and Y = 5,238,338 meters (at Source Number 312). Because the receptors at the minimum grid distance of 0.2 km are entirely within the property boundaries of the smelter (see Figure 7-5), we believe any concentrations calculated at this distance should probably not be used. In the magnetic tape output sent to George Duggan, the shortest distance at which concentration estimates are provided is 0.4 km.

Figures 7-1 and 7-2 are isopleth plots on a map of the Tacoma area of the annual average arsenic concentrations for the Baseline and BAT emissions scenarios. Figures 7-3 and 7-4 are similar isopleth plots on the full 20-km polar grid. Because of the difference in distance scales, not all the isopleths shown in Figures 7-1 and 7-2 are shown in Figures 7-3 and 7-4. Isopleth plots for the area closest to the smelter are presented in Figures 7-5 and 7-6.

To aid in the interpretation of the isopleth plots, we have listed the major source contributions at selected grid points for the Baseline scenario in Tables 7-1 through 7-3. Similar information for the BAT scenario is presented in Tables 7-4 through 7-6. The grid points along the 225.0-deg and 202.5-deg radials represent the maximum concentrations in the Tacoma area at various distances from the smelter. The other grid points are for Vashon Island and Brown's Point.

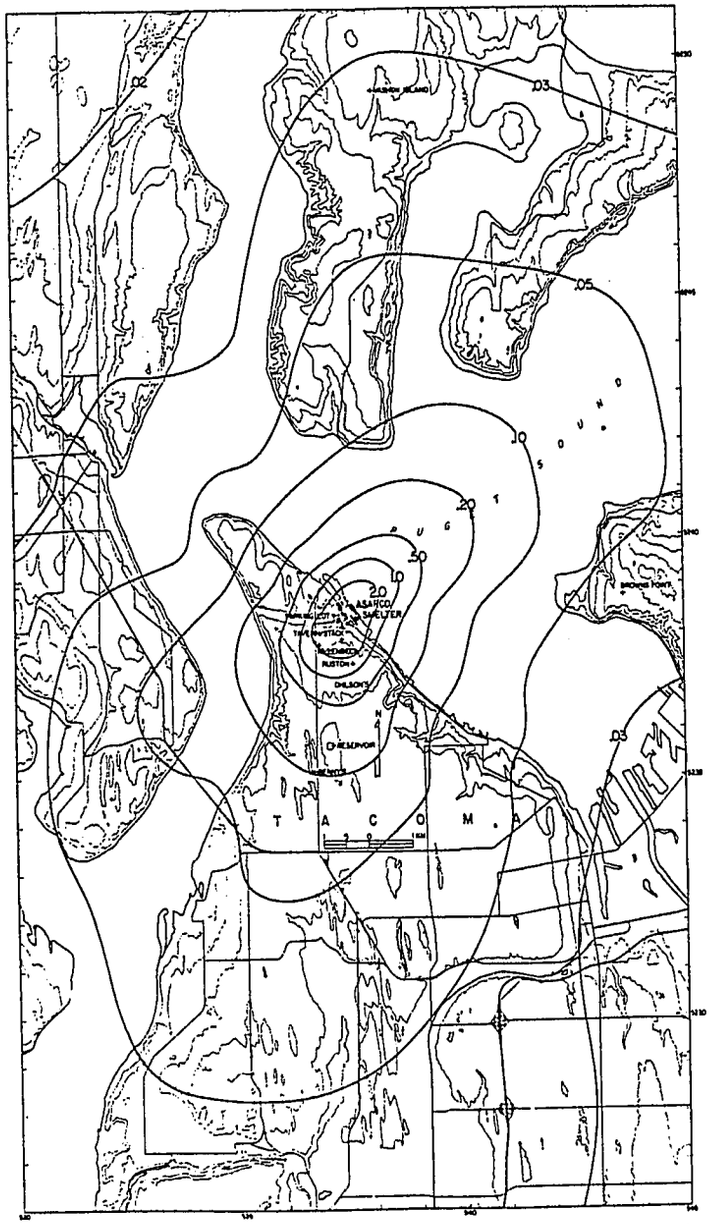

FIGURE 7-1. Annual average arsenic concentration isopleths in $\mu g\ m^{-3}$ for the Baseline emissions scenario with zero background. The UTM coordinates for this Tacoma area grid are shown at the edges of the figure. The UTM coordinates for the grid center are X = 537,434 m and Y = 5,238,338 m.

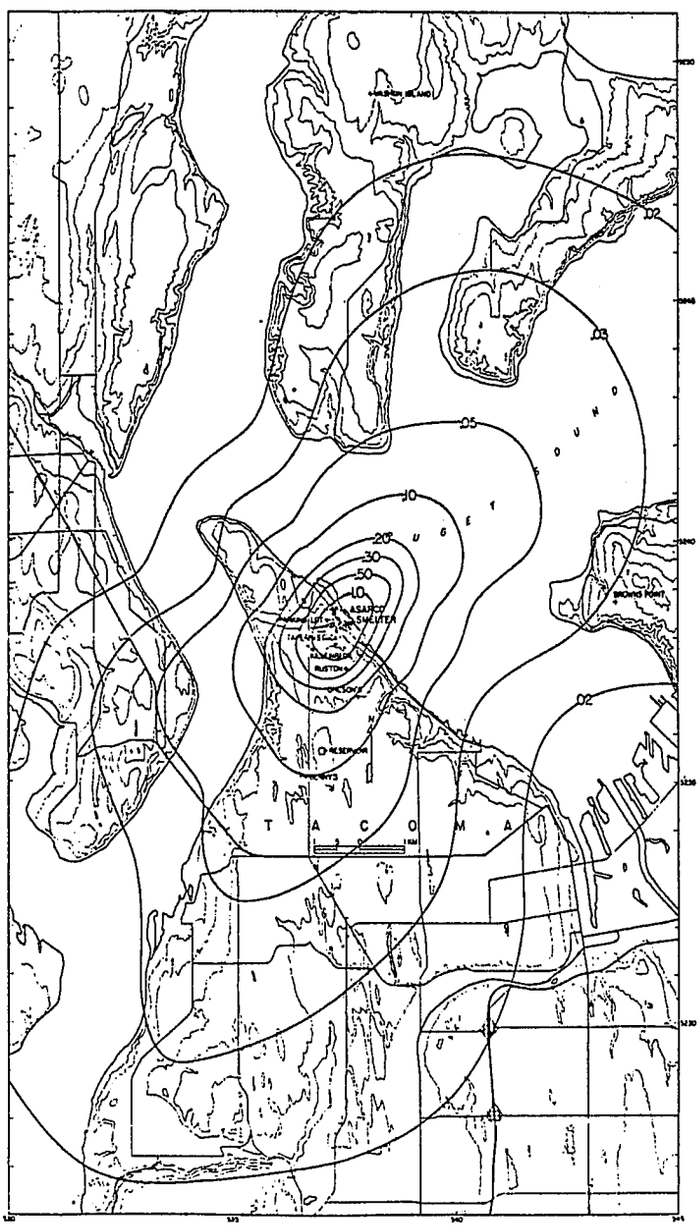

FIGURE 7-2. Annual average arsenic concentration isopleths in μg m^{-3} for the BAT emissions scenario with zero background. The UTM coordinates for this Tacoma area grid are show at the edges of the figure. The UTM coordinates for the grid center are X = 537,434 m and Y = 5,238,338 m.

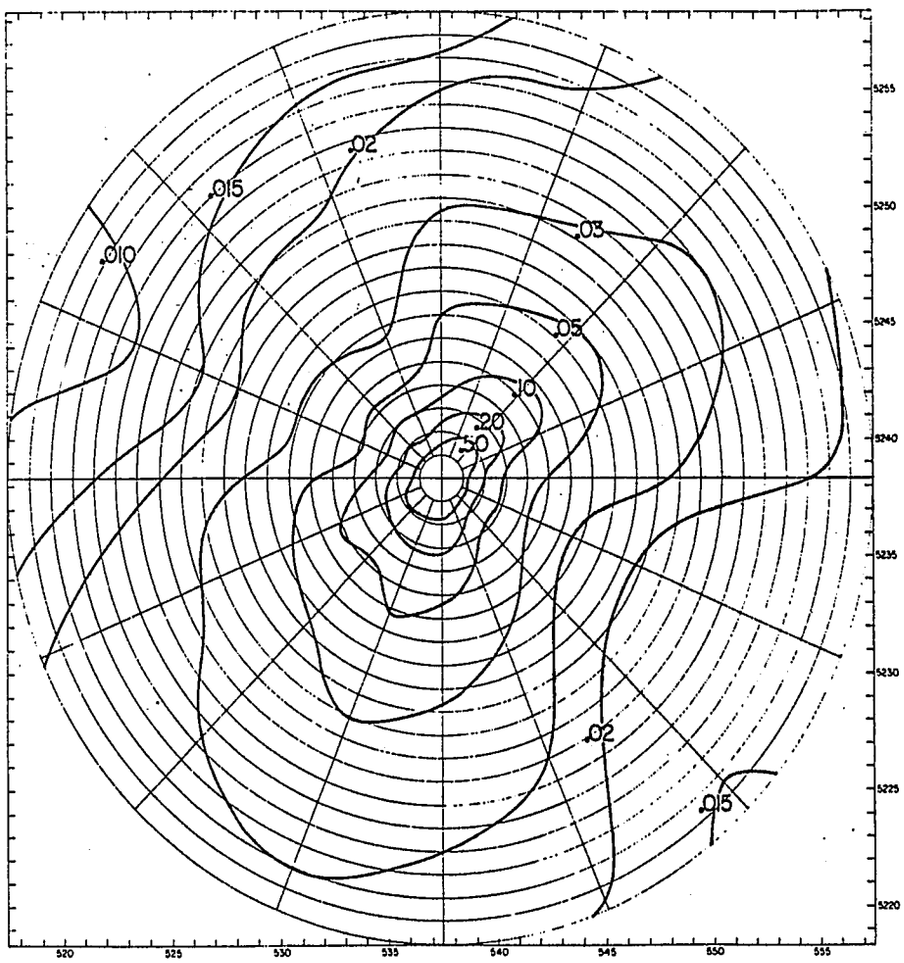

FIGURE 7-3. Annual average arsenic concentration isopleths in μg m^{-3} for the Baseline emissions scenario with zero background. The UTM coordinates for the 20-km polar calculation grid are shown at the edges of the figure. The UTM coordinates for the grid center are X = 537,434 m and Y = 5,238,338 m.

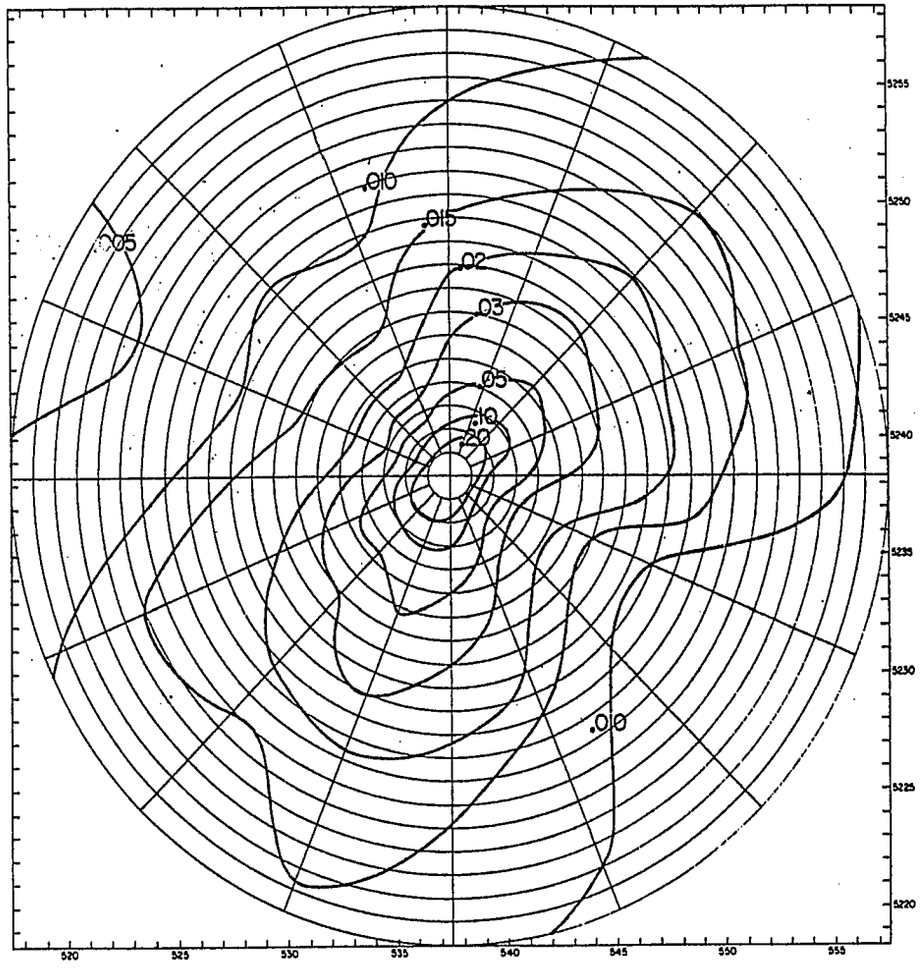

FIGURE 7-4. Annual average arsenic concentration isopleths in $\mu g\ m^{-3}$ for the BAT emissions scenario with zero background. The UTM coordinates for the 20-km polar calculation grid are shown at the edges of the figure. The UTM coordinates for the grid center are X = 537,434 m and Y = 5,238,338 m.

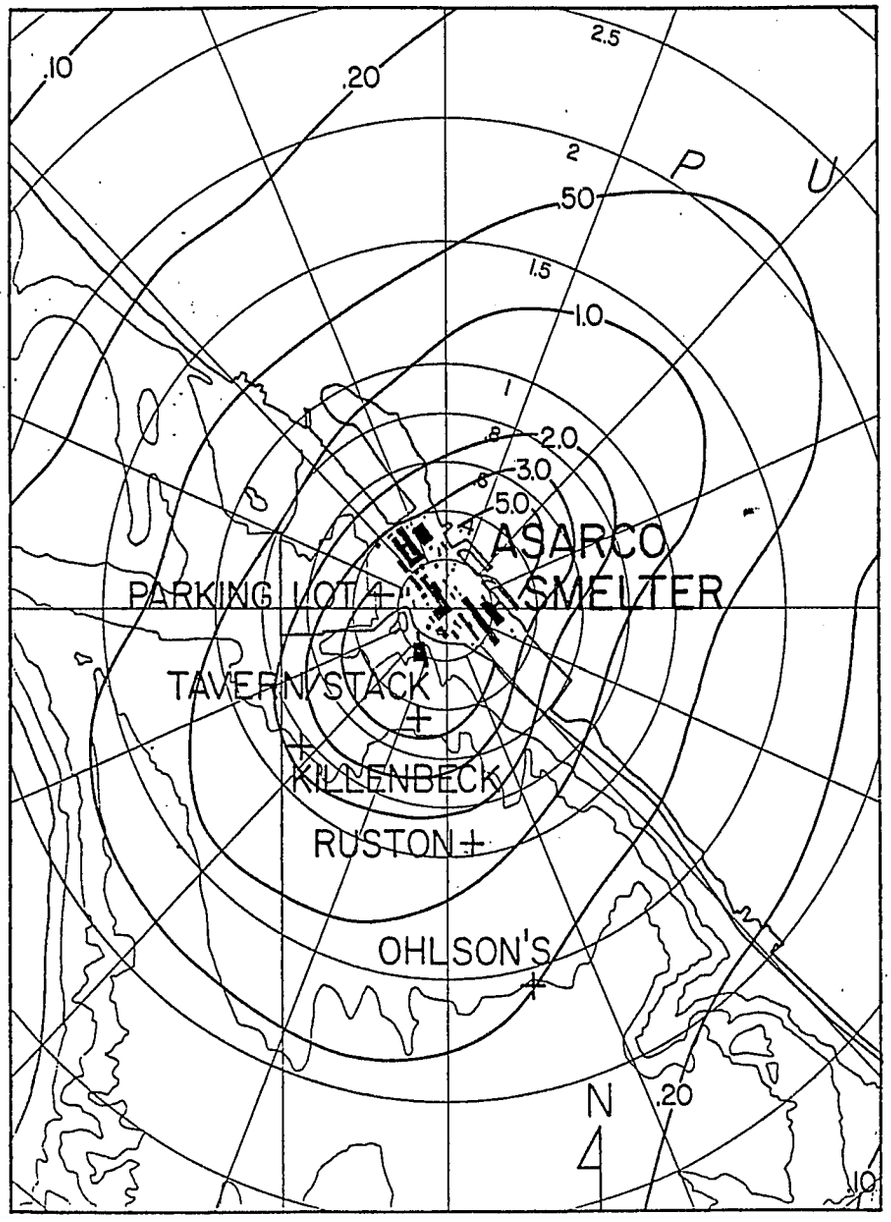

FIGURE 7-5. Annual average arsenic concentration isopleths in μg m^{-3} in the vicinity of the ASARCO smelter for the Baseline emissions scenario with zero background. Distances of polar grid circles are in km.

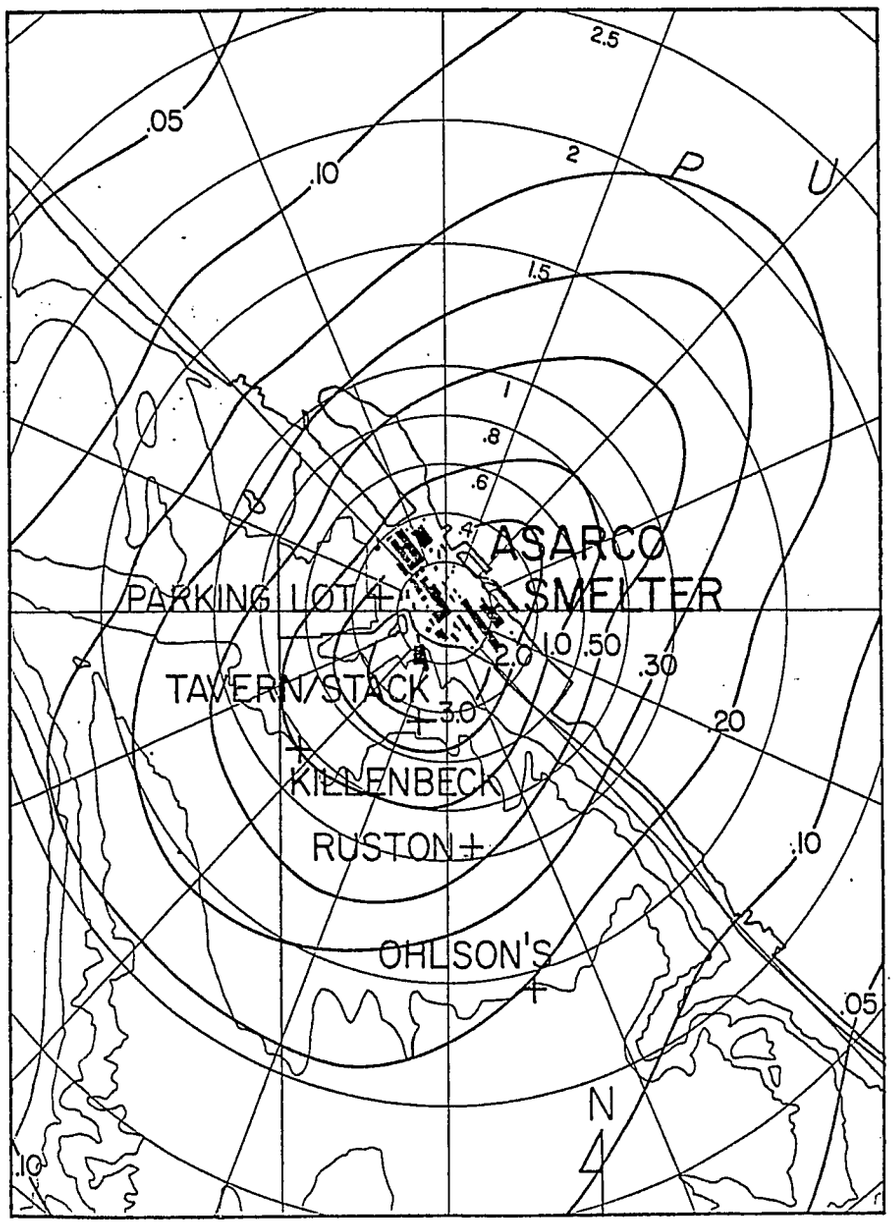

FIGURE 7-6. Annual average arsenic concentration isopleths in μg m^{-3} in the vicinity of the ASARCO smelter for the BAT emissions scenario with zero background. Distances of polar grid circles are in km.

TABLE 7-1

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT SELECTED GRID POINTS FOR THE BASELINE EMISSIONS SCENARIO

Radial (deg)/ Distance (km)	LONGZ Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
225.0/0.6	All Sources	4.0639		
	311-313		2.3592	58.05
	331-332		0.663	16.27
	300		0.6332	15.58
	100		0.0000	0.00
				Total 89.90
225.0/1.0	All Sources	1.6129		
	311-313		0.9689	60.07
	300		0.2484	15.40
	331-332		0.2409	14.93
	100		0.0000	0.00
				Total 90.40
202.5/3.0	All Sources	0.2149		
	311-313		0.1226	57.03
	300		0.0296	13.79
	331-332		0.0268	12.49
	100		0.0171	7.96
				Total 91.27
202.5/6.0	All Sources	0.1023		
	311-313		0.0516	50.50
	100		0.0203	19.88
	300		0.0123	12.02
	331-332		0.0105	10.28
				Total 92.68
202.5/10.0	All Sources	0.0555		
	311-313		0.0280	50.50
	100		0.0112	20.14
	300		0.0066	11.94
	331-332		0.0056	10.16
				Total 92.74

TABLE 7-2

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT SELECTED GRID POINTS FOR THE BASELINE EMISSIONS SCENARIO

Radial (deg)/ Distance (km)	LONGZ Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
202.5/15.0	All Sources	0.0336		
	311-313		0.0171	50.92
	100		0.0069	20.67
	300		0.0040	11.97
	331-332		0.0034	10.27
				Total 93.83
202.5/20.0	All Sources	0.0246		
	311-313		0.0124	50.22
	100		0.0051	20.58
	300		0.0029	11.81
	331-332		0.0025	10.15
				Total 92.76
0.0/3.5	All Sources	0.1033		
	311-313		0.0636	61.60
	300		0.0148	14.31
	331-332		0.0114	10.99
	100		0.0045	4.32
				Total 91.22
0.0/11.0	All Sources	0.0299		
	311-313		0.0166	55.60
	100		0.0041	13.57
	300		0.0039	13.04
	331-332		0.0031	10.23
				Total 92.44
090.0/5.0	All Sources	0.0467		
	311-313		0.0228	48.74
	100		0.0104	22.34
	300		0.0055	11.68
	332-332		0.0047	10.06
				Total 92.82

TABLE 7-3

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT SELECTED GRID POINTS FOR THE BASELINE EMISSIONS SCENARIO

Radial (deg)/ Distance (km)	LONGZ Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
090.0/7.0	All Sources	0.0483		
	311-313		0.0216	44.84
	100		0.0142	29.38
	300		0.0051	10.61
	331-332		0.0042	8.81
			Total	93.64

TABLE 7-4

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT SELECTED GRID POINTS FOR THE BAT EMISSIONS SCENARIO

Radial (deg)/ Distance (km)	LONGZ Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
225.0/0.6	All Sources	1.9123		
	331-332		0.6613	34.58
	300		0.6332	33.11
	311-313		0.2076	10.85
	340		0.1633	8.54
	100		0.0000	0.00
				Total 87.08
225.0/1.0	All Sources	0.7290		
	300		0.2484	34.07
	331-332		0.2409	33.04
	311-313		0.0850	11.66
	340		0.0595	8.16
	100		0.0000	0.00
				Total 86.87
202.5/3.0	All Sources	0.1036		
	300		0.0296	28.62
	331-332		0.0268	25.91
	100		0.0176	16.98
	311-313		0.0109	10.39
	340		0.0068	6.53
				Total 88.43
202.5/6.0	All Sources	0.0557		
	100		0.0209	37.57
	300		0.0123	22.07
	331-332		0.0105	18.86
	311-313		0.0050	8.95
				Total 87.45
202.5/10.0	All Sources	0.0303		
	100		0.0115	38.07
	300		0.0063	20.92
	311-332		0.0056	18.64
	311-313		0.0024	8.06
				Total 85.69

TABLE 7-5

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT SELECTED GRID POINTS FOR THE BAT EMISSIONS SCENARIO

Radial (deg)/ Distance (km)	LONGZ Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
202.5/15.0	All Sources	0.0186		
	100		0.0072	38.48
	300		0.0040	21.69
	331-332		0.0034	18.57
	311-313		0.0015	8.02
				Total 86.76
202.5/20.0	All Sources	0.0135		
	100		0.0052	38.77
	300		0.0029	21.57
	331-332		0.0025	18.53
	311-313		0.0011	8.01
				Total 86.88
0.0/3.5	All Sources	0.0452		
	300		0.0148	32.68
	331-332		0.0114	25.09
	311-313		0.0054	11.96
	100		0.0046	10.21
	340		0.0027	6.06
				Total 86.00
0.0/11.0	All Sources	0.0148		
	100		0.0042	28.32
	300		0.0039	26.29
	331-332		0.0031	20.63
	311-313		0.0014	9.51
	340		0.0007	5.00
				Total 89.75
090.0/5.0	All Sources	0.0263		
	100		0.0108	41.02
	300		0.0055	20.78
	331-332		0.0047	17.88
	311-313		0.0020	7.50
				Total 87.18

TABLE 7-6

MAJOR SOURCE CONTRIBUTIONS TO CALCULATED ANNUAL AVERAGE ARSENIC CONCENTRATIONS AT SELECTED GRID POINTS FOR THE BAT EMISSIONS SCENARIO

Radial (deg)/ Distance (km)	LONGZ Source No.	Calculated Concentration ($\mu g\ m^{-3}$)	Source Contribution	
			($\mu g\ m^{-3}$)	(%)
090.0/7.0	All Sources	0.0290		
	100		0.0146	50.60
	300		0.0051	17.69
	331-332		0.0042	14.68
	311-313		0.0019	6.42
				Total 89.39

As indicated in the legends for Figures 7-1 through 7-4, a zero background concentration has been assumed in all of the annual average calculations. No determination has been made of appropriate background concentrations.

8. SUGGESTIONS FOR IMPROVING MODEL PERFORMANCE

In the discussion in Section 6.3 of the comparisons of model estimates with measurements at the ASARCO monitoring stations, it is pointed out that the model overprediction is greatest at the stations closest to the smelter and least at the most distant stations. Also, analysis of the major source contributions shows that the same sources are the major contributors at almost all monitoring stations. Specifically, the Converters (Source Numbers 311, 313) account for 45 to 68 percent of the total calculated concentration at these stations. The Godfrey Roasters and Material Handling (Source Numbers 331 and 332) and the Reverberatory Furnace (Source Numbers 300) each account for about 15 percent of the total calculated concentration. The above sources thus account for about 80 to 90 percent of the total calculated concentration at all monitor stations. We believe that the model overprediction is principally caused by two factors. One factor is that the emission rates assigned to the Converters, Godfrey Roasters and Material Handling and the Reverberatory Furnace are too high. We suggest an analysis be made of these emission rates to see if there is a basis for significant reductions. The second factor is that the relatively greater model overprediction close to the smelter is caused by underestimates of the effective source height for the above sources. In the model inputs, these sources are treated as building sources and the emissions are assumed to be at ambient temperature, i.e. no allowance is made for buoyant rise. We suggest that the possibility of buoyant rise for these sources be investigated.

There is an additional problem that needs to be studied - the appropriate background concentration to be used at the monitor stations. This is especially important at the more distant monitors because the background estimates obtained from the 1980 measurements are a large percentage of the total calculated concentration at these monitors. Part of this problem may be the threshold arsenic concentration of the low-vol samplers.

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